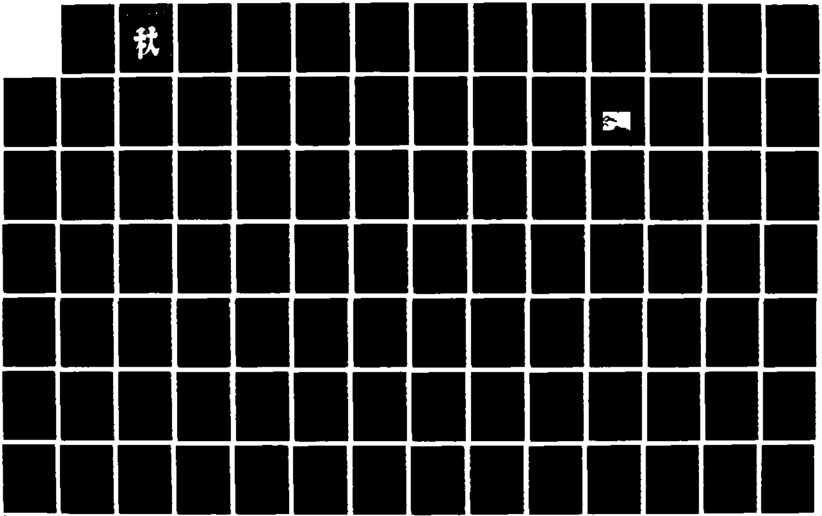
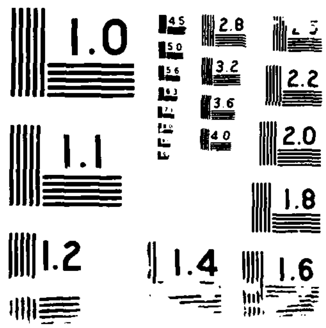
AD-A194 338 ONR FAR EAST SCIENTIFIC BULLETIN VOLUME 12 NUMBER 4 1/2
OCTOBER-DECEMBER 1987(U) OFFICE OF NAVAL RESEARCH
LIAISON OFFICE FAR EAST APO SAN FRANCISCO 96503
UNCLASSIFIED G B WRIGHT ET AL. DEC 87 F/G 5/2 NL




1.0
2.8
2.2
3.2
3.6
2.0
4.0
1.1
1.8
1.2
1.4
1.6

OCTOBER TO DECEMBER 1987 VOL. 12, NO. 4

SCIENTIFIC BULLETIN

DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH FAR EAST
DEPARTMENT OF THE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH FAR EAST
UNITED STATES ARMY RESEARCH OFFICE FAR EAST

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

NAVSO P-3580

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION

1b RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3 DISTRIBUTION / AVAILABILITY OF REPORT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
ONRFE Vol 12, No. 4

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
ONR/AFOSR/ARO

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State, and ZIP Code)
Liaison Office, Far East
APO San Francisco 96503-0007

7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO	TASK NO.	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
ONR FAR EAST SCIENTIFIC BULLETIN

12. PERSONAL AUTHOR(S)
George B. Wright, Director; Sandy Kawano, Editor

13a. TYPE OF REPORT

13b. TIME COVERED FROM ________ TO ________

14. DATE OF REPORT (Year, Month, Day)
October-December 1987

15. PAGE COUNT

16. SUPPLEMENTARY NOTATION
ISSN: 0271-7077

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Alumina matrix, Ceramic bearings, Coastal erosion, Coastal oceanography, Coastal pollution, Curie temperatures, Flares, Fisheries, Japan

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East, the Air Force Office of Scientific Research, and the Army Research Office, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest.

Subscription requests to the Scientific Bulletin should be directed to the Superintendent of Documents, Attn: Subscription, Government Printing Office, Washington, DC 20402. The annual subscription charge is: domestic, $13.00; foreign, $16.25. Cost for a single copy is: domestic, $4.50; foreign, $5.65.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION

22a NAME OF RESPONSIBLE INDIVIDUAL

22b TELEPHONE (Include Area Code)

22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

18. Subject Terms (Key Words) continued

Advanced technology achievements
Aircraft engine bearings
Aluminum nitride matrix
Basic science achievements
Corona research
Creative arts/moral sciences achievements
Engineering schools
Glass-ceramic matrices
India
Ion beam physics
Kyoto Prizes
Magnetism
Mariculture education
Mariculture research
Marine biology
Mullite
Mullite matrix
Mullite strengthening
Oceanography
Organic ferromagnets
Phase equilibria
Powder synthesis and preparation
Radio and x-ray burst
Rolling element bearings
SiC whisker-reinforced ceramic composites
Silicon nitride matrix
Solar physics
Spin coupling
Spinel matrix
Temperature programmed desorption
Zirconia matrix

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

DTIC COPY INSPECTED 7

CONTENTS

Cover: This issue features "Autumn," the last in a series of four Katazome (stencil dyeing) prints from Kichiemon Okamura's "Four Seasons," an expressive rendering of Kanji characters depicting each season of the year.

THE 1987 KYOTO PRIZES

Sandy Kawano

The Kyoto Prizes were established by the Inamori Foundation to honor and recognize the people who have contributed significantly to mankind's betterment mainly in the fields of advanced technology, basic sciences, and creative arts and moral sciences. This year the Foundation honors Dr. Morris Cohen, a preeminent leader in the field of metallurgy; Dr. Jan Hendrik Oort, a renowned astronomer and astrophysicist; and Mr. Andrzej Wajda, an internationally famous film maker.

On 10 November 1987 the third annual presentation ceremony for the Kyoto Prizes was held at the Kyoto International Conference Hall. Their Imperial Highnesses Prince and Princess Mikasa were among the distinguished guests in attendance to honor this year's Laureates, Dr. Morris Cohen, Dr. Jan Hendrik Oort, and Mr. Andrzej Wajda.

The Kyoto Prizes were established by the Inamori Foundation, which was founded in 1984 by Kazuo Inamori, chairman of the Kyocera Corporation. The Inamori Foundation was established to encourage and reward outstanding contemporary intellectual and artistic achievements. The aims of the Foundation are to honor and recognize creative activity and to provide concrete support for significant achievements and research. To further these aims, the Foundation has established the Kyoto Prizes as an incentive to outstanding achievement and creativity and has initiated a wide range of activities designed for the support and encouragement of research. These activities include grants for basic research support, research abroad, invitation of scholars from abroad, and research and cultural exchange. Mr. Inamori endowed the Foundation with a gift of about ¥20 billion in cash and Kyocera stock to support the Kyoto Prizes and these grants.

At the focus of Foundation activities are the Kyoto Prizes. It is the Foundation's intent and hope that the Kyoto Prizes will: (1) become internationally recognized as the highest possible accolade for genius and excellence in scholarship; (2) stand as a pinnacle reward for outstanding achievement in advanced technology and basic sciences; and (3) come to be regarded, in the area of the humanities, as the international hallmark of recognition for significant achievements and contributions in the creative arts, as well as in the philosophical, moral, and spiritual areas of our common human tradition.

The Kyoto Prizes, which were first awarded in 1985, are presented annually in the major categories of Advanced Technology, Basic Sciences, and Creative Arts and Moral Sciences. Specific fields from each category are selected annually (this year's fields are Materials Science, Earth Sciences and Astrophysics, and Cinema/Theater). Then candidates are nominated by official Kyoto Prize nominators, recipients are selected and approved, and the awards are announced in June. Each recipient receives the Certificate of Recognition, a medal, and the Prize money (¥45,000,000).

Dr. Morris Cohen, the Laureate in Advanced Technology (Materials Science), was born in Chelsea,

Massachusetts, in 1911. Dr. Cohen received his S.B. degree from the Massachusetts Institute of Technology (MIT) in 1933 then continued on at MIT to receive a Doctor of Science degree in metallurgy in 1936. He began his professional work in 1937 as an assistant professor of metallurgy at MIT, then rose to associate professor (1941-46) and professor (1946-62). In 1962 Prof. Cohen was appointed Ford Professor of Materials Science and Engineering. In 1975 he became Institute Professor, and in 1982 he was bestowed the title of Institute Professor Emeritus.

Prof. Cohen has devoted his life to education and research in materials science and engineering, particularly in physical metallurgy, and now he is the preeminent academic leader in these fields. His research work has created broad and basic new insights into phase transformations and structure-property relationships in materials. He has played a key role in the following areas: the mechanism and kinetics of martensitic and bainitic transformations, tempering phenomena and strengthening mechanisms in ultra-high-strength steels, solid-state alloy thermodynamics, age hardening in alloys, deformation-enhanced diffusion, brittle fracture mechanisms in heterogeneous materials, mechanisms of strain hardening and dynamic recovery, strain-induced transformation and transformation plasticity, grain refinement mechanisms in microalloyed steels, and rapid solidification of crystalline alloys. His research not only laid the scientific groundwork for all of the ultra-high-strength steels in use today, but he is also responsible for advanced materials science research in areas such as shape-memory phenomena and transformation plasticity in metallic, ceramic, and biological systems.

Prof. Cohen has contributed extensively to international programs as well as national projects. He has visited many countries to lecture and advise, and he has been recognized by over 20 major international awards, honorary degrees, and professorships. His tremendous compassion, intellect, and energies have propelled him to the leadership position that he has now and have made him an inspiration to two generations of students and colleagues in the field of materials science and engineering.

Prof. Jan Hendrik Oort, the Laureate in Basic Sciences (Earth Sciences and Astrophysics), was born in 1900 in Franeker, The Netherlands. After graduating from the University of Groningen in 1921, Prof. Oort became an assistant from 1921-22. In 1922 he served as a research assistant at the Observatory of Yale University, then from 1924-30 he was the conservator at Leiden Observatory. Prof. Oort received a Doctor of Science degree from the University of Groningen in 1926. In 1935 he accepted a professorship in astronomy at Leiden University, and in 1945 he also became the director of the Leiden Observatory. Prof. Oort served in both positions until 1970, when he was honored with the title of Professor Emeritus. Also during that time (1958-61), he served as president of the International Astronomical Union.

Prof. Oort has been awarded the Kyoto Prize for his long-standing contributions to astronomy and astrophysics, particularly for his elucidation of the structure and dynamics of the galaxy. He found that the Milky Way is a large stellar system with a disk shape and rapid rotation, in which the sun is located about two-thirds of its radius away from the center. Prof. Oort derived this structure in the late 1920s from optical observation of the

velocities of stars and later quantified it (in the 1950s) by radio observation of the 21-cm hydrogen line. The galactic rotation is characterized by a pair of parameters called the Oort constants, and the motion perpendicular to the galactic disk is dictated by the Oort mass limit, which is the maximum permissible surface mass density in the solar neighborhood.

One of his important contributions to astronomy was the development of radio astronomy. Prof. Oort initiated the 21-cm observation independently of Purcell and designed radio telescopes including interferometers. Using these radio telescopes, he has found high velocity hydrogen clouds falling on the galaxy, expanding features in the galactic center, and various interesting properties of external galaxies. Prof. Oort has also derived the distance to the galactic center, referring to radio and optical data.

In solar system studies in 1950, Prof. Oort showed that there is a nest of comets, called the Oort cloud, at 100,000 AU from the sun that supplies comets when disturbed by passing stars.

Prof. Oort has also devoted himself to the study of supernovae. One of his most striking discoveries was the polarization of light from the Crab Nebula, a remnant of supernova 1054. This proved the theoretical prediction that the electromagnetic emission is due to the synchrotron radiation by relativistic electrons in magnetic fields.

Prof. Oort's scientific achievements have been recognized by several prizes, memberships in several academies, and honorary degrees. His scientific research achievements and enthusiasm, which has let him continue his work to this day, have been an inspiration to astronomers and astrophysicists all over the world.

Mr. Andrzej Wajda, the Laureate in Creative Arts and Moral Sciences (Cinema/Theater), was born in Suwalki, Poland, in 1926. He was 13 when the Nazis invaded Poland, and at 16 he joined the Polish resistance. After the liberation, Mr. Wajda studied painting at the Academy of Fine Arts in Krakow and then dramaturgy at Leon Schiller State Theatre and Film School in Lodz. After graduating in 1954, Mr. Wajda made a series of works, "A Generation," "Canal," and "Ashes and Diamonds," called the Three Resistance Series because the films depict the tragic experiences of his fellow countrymen during and after the war. These works, which vividly portray the way in which fighting and survival situations affect human beings, won worldwide acclaim.

In addition to his "realistic" series, Mr. Wajda has also made a romantic series of films including "Innocent Sorcerers," "Birch Wood," and "The Maids of Wilko," which lyrically express the sorrows and joys of youth. In such films as "Ashes," "The Gates of Paradise," "Land of Promise," and "Danton," Mr. Wajda has used a historical theme to depict human aspirations and frustrations.

The consistent image that runs through all these wide-ranging styles and themes in Mr. Wajda's works is that of deeply motivated persons who confront and challenge major hardships. In his films Mr. Wajda has tried to penetrate and explore the intricacies of human nature. The films "Man of Marble" and "Man of Iron" also contain powerful expressions of the way people have lived under the political and social reform in Poland. Some of his films were produced outside Poland, such as "Danton" in France and "A Love in Germany" in Germany.

Mr. Wajda has also excelled in other areas of theater arts, such as acting and directing. In 1980 at the

International Film Festival in Berlin he was voted Best Actor for his role in "The Conductor." At the International Film Festival in Moscow in 1971 he received the Best Director award for "Birch Wood," and at Cesars 1982 he was voted Best Director for his production of "Danton."

Mr. Wajda's 60th birthday was commemorated in 1986 with "The Exhibition—The Theatre of Andrzej Wajda" and "The Exhibition—Andrzej Wajda's 30 Films 1954–1985," held in various places in Poland. He has recently released "A Chronicle of Amorous Accidents" and is filming "Devils" in France.

Mr. Andrzej Wajda has made a lasting contribution to the field of cinema arts by continually releasing outstanding films made with deep sensitivity and elaborate compositional power. His films appeal strongly for human dignity and freedom of spirit, and his personal commitment to these ideals prompted his resignation from the public offices of president, Polish Film Association, and representative, Film Unit X. We can expect a continuing flow of Mr. Wajda's creative activity in the future.

According to Mr. Kazuo Inamori, president of the Inamori Foundation, "man has no higher calling than to work for the greater good of all humankind." The achievements of this year's recipients of the Kyoto Prizes exemplify that ideal by contributing significantly to mankind's scientific, cultural, and spiritual betterment.

Sandy Kawano is the editor of the Scientific Bulletin. *Before coming to Japan, she worked for the Naval Civil Engineering Laboratory, Port Hueneme, California, as a Technical Writer-Editor. She has a Bachelor of Arts degree in Liberal Studies from California State University, Northridge.*

ORGANIC FERROMAGNETS

Minoru Kinoshita and Earl Callen

Researchers have now succeeded in synthesizing ferromagnets entirely from organic elements--carbon, hydrogen, oxygen, and nitrogen. Curie temperatures, the temperature below which the material is spontaneously magnetically ordered, are above room temperature. So far yields are low, of the order of a percent or less, and the precise composition of the ferromagnetic component is only guessed at. Two steps are necessary: to synthesize stable molecules with unpaired spins and to cause these spins to couple ferromagnetically. Molecular systems with unpaired spins are formed by some researchers by using charge transfer compounds. Other groups use radicals with a spin triplet ground state. Ferromagnetic coupling is achieved by attaching radicals to hydrocarbon chains with π electrons. The same kind of "free electron" mobility that allows for other metallic behavior in organics--high electrical conductivity, superconductivity--may also allow the indirect exchange interaction that is the source of ferromagnetism in the transition metals.

When we think of magnets we usually think of iron. The ancients did not; they thought of lodestone. And centuries before the Greeks discussed lodestone the Chinese were shaping it into needles and making compasses for marine navigation. While iron is a metal, lodestone--today we call it magnetite--is a ceramic. It is the base of the memory cores for computers.

The element that makes magnetite magnetic is iron. Iron, nickel, and cobalt, elements of the first transition series, are magnetic because their atoms contain an only-partially-filled 3d shell. Ordinarily, energy levels are filled two electrons per level, one with spin up and one with spin down. That is all Pauli exclusion will allow. The next two electrons must fill the next level up, of higher energy. But in an unfilled shell there are degenerate orbital levels of the same energy. These can be filled by electrons of parallel spins without cost in orbital energy. This is Hund's rule. The arrangement "of maximum multiplicity"--with parallel spins--has the lowest intra-atomic exchange energy. Parallel spins means net spin angular momentum and magnetic moment--magnetic atoms. Further along in the periodic table at the lanthanides there is again a level inversion and a partially filled 4f shell, and atoms with magnetic moments. Today we have rare earth magnets, technologically important ones such as $SmCo_5$, and the even-more-important $Nd_2Fe_{14}B$. And still further along, at the actinide level, an incomplete 5f shell leads to the exotic magnetic behavior of uranium and its neighbors.

Since magnetism originates in unfilled orbital angular momentum shells, one might wonder about the orbital contribution to the angular momentum and magnetic moment, in addition to the uncompensated electron spin. In solids the orbital angular momentum of electrons in the 3d shell is largely negated by the electric field of neighboring ions. In the lanthanides and actinides the orbital contribution to the elementary magnetism of an individual atom can add considerably to the contribution from electron spin.

Atomic moments interact with each other. There is always the classical, weak but long range, magnetic dipole-dipole interaction. It is proportional to the entire dipole moment of the atom, not just its spin. "Opposite poles attract." The tendency of the dipolar interaction is to cause the atomic moments to order in some sort of looped, closed arrangement, or antiferromagnetic arrangement, which brings north and south magnetic poles near each other. When there are no other forces between the atomic moments, this ordering will occur only at a sufficiently low temperature--a fraction of a degree--that the dipolar energy exceeds kT. But in the right circumstances there can also be an electronic, quantum mechanical, "exchange" interaction, and it can be very much larger than the classical dipole interaction. Exchange relates back to the spins, whether there is orbital angular momentum or not. Exchange coupling can be either ferromagnetic--all the spins lie parallel to each other--or antiferromagnetic--any long range ordered structure with no net moment.

And so we have ferromagnets, like iron (even in such a case the dipolar interaction asserts itself by creating "domains"--macroscopic regions in which the magnetization rotates from one to the next, so that the magnetic flux closes on itself inside the material). We have antiferromagnetic insulators, like NiO, in which, because of "superexchange," successive spins point alternately "up" and "down," and we have more complicated arrangements. Magnetite is an example of a ferrimagnet, with several kinds of atomic sites with different numbers of atoms per unit volume and different kinds of atoms on the various sites. In such a material, on some sites the moments can point up and on others down, but the moments of these several "sublattices" need not cancel, as in an antiferromagnet. There are even more complicated arrangements. In the rare earth metals the atomic moments order in exotic angled structures--spiral staircases; progressively opening, blown-out, and closing umbrellas; three-dimensional standing spin waves whose wavelength is incommensurate with the crystal lattice. But in all antiferromagnetic structures there is no net moment. Over a wavelength the moments cancel out.

There is a characteristic temperature at which the thermal energy equals the exchange energy, the energy of interaction between the spins. Below this temperature the moments are ordered and above it they are not. When the ordering is ferromagnetic the ordering temperature is called the Curie temperature, T_C; when the ordering is antiferromagnetic the transition temperature is called the Néel temperature, T_N. Above the phase transition the material is paramagnetic; thermal energy tumbles the moments around so that they point in random directions and average out to zero. Only by application of a magnetic field can a moment be induced. In the paramagnetic phase the induced moment is proportional to the external field strength, and the proportionality constant, the susceptibility χ, has a temperature dependence that follows the Curie-Weiss law:

$$\chi = \frac{C}{T - \theta}$$

Here C is a constant (proportional to the square of the atomic magnetic moment); T is the absolute temperature; and θ, the "paramagnetic Curie temperature," is a measure of the exchange interaction. Positive θ means ferromagnetic exchange; negative θ means antiferromagnetic interaction. The paramagnetic Curie temperature is

not a physical quantity. It is not the temperature at which the phase transition to the ordered phase actually occurs; it is the extrapolated intercept on the temperature axis, on a plot of the reciprocal of the susceptibility versus temperature, at such temperatures far enough above the transition that the Curie-Weiss law is obeyed. For ferromagnets the actual transition temperature, T_C, is usually not too far from θ. In the case of antiferromagnets the actual transition temperature, T_N, is often something like $-\theta$.

Whether the magnetic arrangement is ferromagnetic or antiferromagnetic, the materials are either metals or insulators and the atomic moments in all cases come from atoms with unfilled shells. Is there any other way to be magnetic? Can magnets be made of atoms with filled shells? Are there organic ferromagnets? That is a natural question in a time of organic semiconductors and ceramic and organic superconductors. Some bacteria are magnetic; they use it to sense the earth's magnetic field for navigation, as do some birds and fish. But all these get their magnetism by incorporating tiny, single domain particles of magnetite. Can ferromagnets be constructed wholly of H, C, N, O, and such? The question resolves itself in two. Unlike metals, organic solids consist of distinct, separable clusters--molecules. So what is needed, first, is for the individual molecules to have magnetic moments. And second, the moments of the molecules must interact ferromagnetically. (Given molecular moments it will be no trick at all to get antiferromagnetic ordering--at some low temperature the dipole-dipole interaction will take care of that. The interesting challenge is to create organic ferromagnets.)

Let's start with the first step, getting the dipole moment. Most organic molecules are diamagnetic. The simplest molecule of all, the homopolar diatomic molecule, H_2, illustrates the problem. Its two electrons go into the lowest bonding orbital, one with spin up and one with spin down, a spin singlet--no moment. There is always that strong tendency, but there are exceptions; the ground state of O_2 is a spin triplet (the two outer electron spins are parallel). In fact how about a heteropolar molecule with an odd number of electrons, like NO? NO must be at least a Kramers doublet. That's step one (except that molecules with unpaired spins often cluster in pairs to lower their energy, with one spin up and one spin down again; we will run into this problem later when we discuss galvinoxyl). How about step two? No. In the molecular crystals composed of simple small molecules like O_2 and NO, only the dipole-dipole interaction couples the moments. They order antiferromagnetically.

Ferromagnetism means exchange, which means some sort of electron transfer, or resonance, or valence fluctuation, or electrical conduction. But spin coupling through electron resonance between localized orbitals is almost always antiferromagnetic. (This is again because of the Pauli principle. Superexchange can in principle produce ferromagnetism, but only under circumstances not often realized, and then involving degenerate levels--which means unfilled shells again.) What one needs for ferromagnetic exchange is nonlocalized electrons--π electrons free to wander--the same property that characterizes the organic semiconductors with high electron mobility and the organic metals and superconductors. With luck it might happen that π electrons travelling along and between polymer chains might scatter off localized electron spins, thereby providing the same sort of ferromagnetic indirect exchange interaction as the Rudermann — Kittel — Kasuya — Yosida (RKKY) interaction in metals.

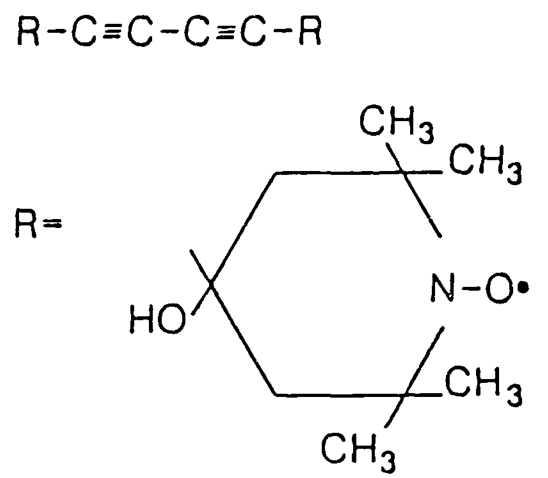
Organic ferromagnets seem to have been first discussed by McConnell. In his 1963 paper (Ref 1) McConnell suggested building from a molecule with a net spin moment and spin polarization, such as the allyl radical. His idea was to arrange these in staggered, alternating layers, for exchange coupling reasons. Such a scheme has never been realized, and by 1967 McConnell had presumably rethought the problem and proposed formation of the molecular moment by charge transfer (Ref 2). He conjectured as follows: Suppose an organic solid consists of two kinds of components, one of which has a triplet ground state, as did our illustrative example O_2 and as do cyclopentadienyl (Ref 3) and diphenylcarbene (Ref 4). Now suppose that the solid is ionic, consisting of cation and anion radicals of the two components. Configuration interaction might then mix the triplet ground state in with a triplet ionic state and produce ferromagnetically coupled radicals. One line of search has followed that reasoning, either directly or in modified form (Ref 5). Another approach, that of Mataga (Ref 6), and the more successful so far, has been to form the molecular moment on neutral radicals, and attach these to conjugated long chain pseudo-one-dimensional polymers that allow for π electron mobility. Yoichiro Sato (Ref 7), in an unpublished dissertation, also considered both the neutral radical and charge transfer mechanisms for obtaining unpaired spins in organic systems and discussed the exchange interaction.

Neutral radicals with spins coupled by metallic exchange has also been the 10-year goal of Ovchinnikov (Ref 8), and now he and his coworkers have indeed produced an organic ferromagnet (Ref 9). The Russians use the much-studied TEMPO radical (2,2,6,6-tetramethyl-4-oxy-4-piperidyl-1-oxyl) and construct the biradical monomer diTEMPO-DA (see Figure 1a). diTEMPO-DA, which the Russians understandably refer to as BIPO, is a paramagnet and follows the Curie-Weiss law. The paramagnetic Curie temperature is negative, about -2 K. This suggests that BIPO will order antiferromagnetically at some low temperature. (In crystals of these pseudo-one-dimensional molecules the exchange interaction is extremely anisotropic, and the actual three-dimensional ordering occurs at temperatures far below what one might naively expect from the Curie-Weiss intercept.) And indeed it does; below the Néel temperature monomer BIPO is an antiferromagnet.

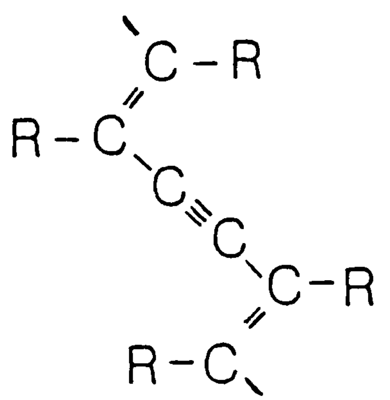
Ovchinnikov and coworkers then polymerize BIPO by exposure to heat, ultraviolet radiation, or a glow discharge and are able to convert between 80 and 100 percent of the monomer to polyBIPO. In polyBIPO the nitroxyl radicals attach to a polydiacetylene chain, perhaps as illustrated in Figure 1b. And polyBIPO is indeed ferromagnetic—or at least 0.1 percent of it is! The Russians quote Curie temperatures ranging from 150 to 190 °C and with indications of ferromagnetic behavior in some fractions up to 310 °C. They conjecture that the low ferromagnetic fraction, the low moment, and the variable Curie temperature may be due to some sort of spin glass formation.

Torrance and coworkers (Ref 10) at IBM San Jose have followed the McConnell charge transfer logic and have achieved success at about the same time as the Russians. Symmetrical 1,3,5-triaminobenzene is reacted with iodine at room temperature. The reaction is complex; there seem to be several reaction paths; the constituents and properties of the resultant black, insoluble polymer vary from batch to batch; and about 2 percent of the final product is ferromagnetic. Torrance

conjectures that this ferromagnetic component is a partially oxidized <u>meta</u>-linked phenyl polymer. Magnetization versus field curves at room temperature look like typical magnetization curves of a soft ferromagnet (very little hysteresis) of low saturation moment. Interpretation of the magnetization versus temperature curves, particularly at higher temperatures, is complicated by the irreversible thermal decomposition of the polymer between 300 and 400 °C. But the Curie point is certainly above room temperature.



(a) Monomer diTEMPO-DA, or BIPO, and the stable nitroxyl radical TEMPO.



(b) PolyBIPO.

Figure 1. The Ovchinnikov method.

Joel Miller of DuPont, in collaboration with Arthur Epstein of Ohio State, Columbus (Ref 11), follows the charge transfer route to attain unpaired spins. They construct a crystal of the donor organometallic ferrocene molecule, decamethylferrocene, and the acceptor molecule, tetracyanoethylene. And at about 5 K the spins do indeed align ferromagnetically. One might protest that Miller and Epstein are breaking the rules—ferrocene contains an iron atom. The iron <u>moment</u> is probably not essential to the ferromagnetism (although the d level degeneracy may very well be). Miller and Epstein would argue that the iron atoms are so far apart as to preclude overlap of their wavefunctions; the moment is the odd electron spin, and the coupling is carried through nonlocalized electrons.

At least two Japanese groups have been active. We mentioned earlier that diphenylcarbene is a spin triplet (Ref 4). Because of the large intra-atomic exchange, i.e., Hund's rule, the two outer electron spins go in *parallel in almost degenerate molecular* orbitals of divalent carbon in certain cojugated hydrocarbon structures (Ref 6, 12). And so, by hooking together hydrocarbons, replacing a C–H on each unit by a divalent C, it should be possible to create arbitrarily long molecular chains with two parallel spins on each link. Wasserman et al.; Koichi Itoh and Takeji Takui, of Osaka City University; and Hiizu Iwamura, Tadashi Sugawara, and coworkers at the Institute for Molecular Science, Okazaki, have been investigating progressively higher homologs of such series (Ref 13–16). They have succeeded in hooking together four (Ref 15) and five (Ref 16) carbenes in high spin (S=4 and S=5) states (see Figure 2). These high spin molecules are extremely reactive. The trick will be in bringing them together in such a way that they do not react chemically, but yet their spins couple ferromagnetically.

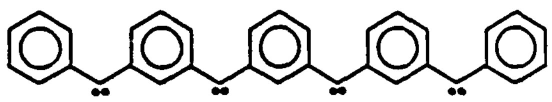


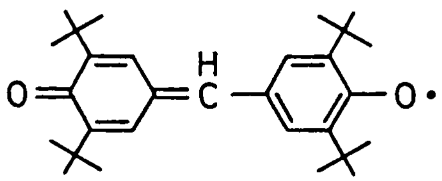
Figure 2. The Itoh and Iwamura method. Polycarbene: chain of four phenylcarbenes. Each phenylcarbene radical contains two localized electrons with spins parallel.

The Iwamura group has experimented with dispersing the polycarbenes with alkyl chains. They introduce octyloxy groups at the para positions of diphenyldiazomethane (Ref 15). This keeps the carbenes apart and is believed to orient them properly for ferromagnetic exchange (Ref 17). But so far this line of attack has not been successful. Electron spin resonance (ESR) and susceptibility measurements show that the carbenes are indeed in the high spin state, but the magnetic interactions between chains are complex. There seem to be both ferromagnetic and antiferromagnetic interactions, and the polymers do not order ferromagnetically at any temperature.

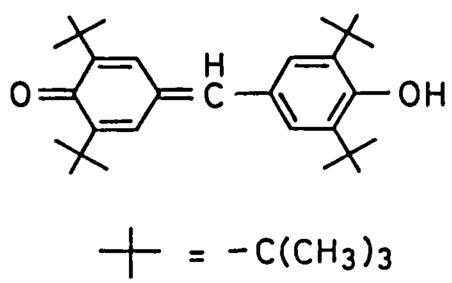
Kunio Awaga, Tadashi Sugano, and Minoru Kinoshita of the Institute for Solid State Physics, University of Tokyo (Ref 18), work with the stable free radical galvinoxyl (4-((3,5-bis(1,1-dimethylethyl)-4-oxo-2,5-cyclohexadien-1-ylidene)methyl)-2,6-bis(1,1-dimethylethyl)phenoxy) (see Figure 3a). There is no orbital contribution to the moment of its one unpaired spin, so the moment is that of S=1/2. In the crystalline state galvinoxyl molecules stack along the c-axis to form one-dimensional columns. The temperature dependence of the paramagnetic susceptibility of crystals of galvinoxyl follows the Curie-Weiss law, with a positive paramagnetic Curie temperature of 19 K. But as the temperature is reduced, at 85 K, the crystal undergoes a first order phase transition, evidently of magnetic and magnetoelastic origin. Below the transition the crystal displays only a much reduced, but still positive, magnetic susceptibility. What seems to be happening is that at the phase transition pairs of galvinoxyls in the stack pull together, with their unpaired spins coupled antiferromagnetically in a ground state singlet. The triplet spin state of each sandwich, which lies only a little above the singlet, can be excited thermally. This is seen in ESR absorption. The small remnant paramagnetic moment below the phase transition appears to be due to those occasional, isolated galvinoxyls caught between coupled pairs in the stacks. These left-over molecules account for the observed ESR doublet resonance.

The approach of the Tokyo group has been to suppress the phase transition by dilution. Hydrogalvinoxyl (see Figure 3b), a precursor of galvinoxyl, but with paired spins and no moment, crystallizes in an identical structure but undergoes no phase transition. In solution, the two compounds mix freely in any ratio, for example, six parts galvinoxyl to one part hydrogalvinoxyl, and crystals of the mixture are easily grown. In the stacks of molecules in the crystal there should then be a random distribution of components peaked around the average spacing, six galvinoxyls separated by a hydrogalvinoxyl. If it occurs—as it does—that the unpaired spins of a galvinoxyl segment form a ferromagnetic unit, like a single large molecular moment, and the hydrogalvinoxyls break the chains, then magnetization measurements should reveal a Gaussian distribution of moments peaked at J=S=3 (on average, six molecules in a unit, each with spin 1/2, times the Bohr magneton, of course). In crystals containing 85 percent galvinoxyl or less, the magnetic phase transition is suppressed to below 2 K. The

paramagnetic clusters again obey a Curie-Weiss law, with positive and only slightly reduced temperature intercept, 14 K or so (see Figure 4). In the diluted crystal the ESR spectrum shows that the ferromagnetic interaction has been preserved; the ground state is the triplet, and the singlet lies slightly above. ESR also reveals a much increased number of doublets. The introduction of hydrogalvinoxyl increases the number of galvinoxyls that are left out of a pair, for example in segments of an odd number of galvinoxyls. The Tokyo group is studying under what conditions ferromagnetic intermolecular interaction is possible. All of this has been deeply revealing, but so far no ferromagnetism.



(a) The molecular structure of galvinoxyl.



(b) Hydrogalvinoxyl.

Figure 3. The Tokyo method.*

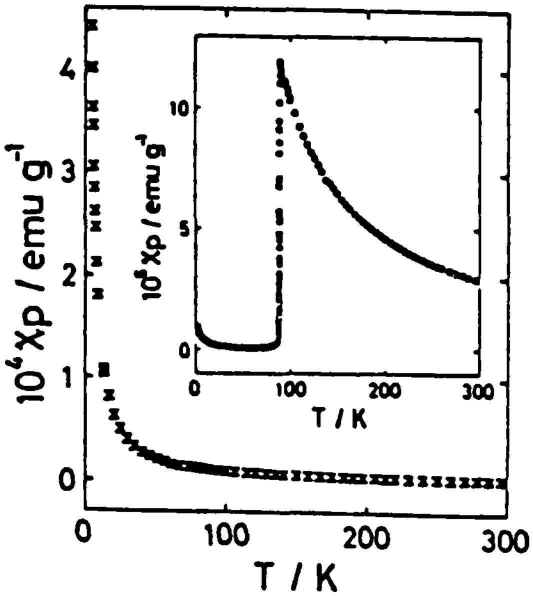


Figure 4. The temperature dependence of the magnetic susceptibility of the 6:1 mixed galvinoxyl/hydrogalvinoxyl crystal. The insert shows the susceptibility of pure galvinoxyl.*

One may ask where the quest for organic ferromagnets will lead. It seems likely that in the not-too-distant future we will know how to produce organic ferromagnets with Curie points above room temperature, or tailored to need, and with significant yields, not the 0.1 or 2 percent now obtained. Whether these will have sufficiently high saturation moments, or be stable, or be cheap, or lightweight, or have unique biological or medical applications, or some other as-yet-unforeseen attractive feature, is an open question, one that in the writers' opinion it is too soon to ask. (But we would not bet on organics as substitutes for iron magnets.) We also think that is the wrong way to phrase the question. The

*Reprinted with permission from Solid State Communications 57 (6), K. Awaga, T. Sugano, and M. Kinoshita, "Organic Radical Clusters with Ferromagnetic Intermolecular Interactions," Copyright 1986, Pergamon Journals Ltd.

right question is: "Is the search for organic ferromagnets a fruitful one?" The answer to that question is already in. The quest has opened up whole new fields of inquiry and yielded whole new classes of compounds. And it is far from over.

REFERENCES

1. H.M. McConnell, J. Chem. Phys. **39**, 1910 (1963).

2. H.M. McConnell, *Proceedings of the R.A. Welch Found. Conf.* 11, 144 (1967).

3. M. Saunders, R. Berger, A. Jaffe, J.M. McBride, J. O'Neill, R. Breslow, J.M. Hoffman, C. Perchonock, E. Wasserman, R.S. Hutton, and V.L. Kuck, J. Am. Chem. Soc. **95**, 3017 (1973).

4. R.W. Brandon, G.L. Closs, and C.A. Hutchison, Jr., J. Chem. Phys. **37**, 1878 (1962); R.W. Murray, A.M. Trozzolo, E. Wasserman, and W.A. Yager, J. Am. Chem. Soc. **84**, 3213 (1962); C.A. Hutchison, Jr., and B.E. Kohler, J. Chem. Phys. **41**, 1763 (1969).

5. R. Breslow, B. Juan, R.Q. Kluttz, C-Z. Xia, Tetrahedron **38**, 863 (1982); R. Breslow, Pure and Applied Chemistry **54**, 927 (1982); R. Breslow, Mol. Cryst. Liq. Cryst. **125**, 261 (1985).

6. N. Mataga, Theor. Chim. Acta **10**, 372 (1968).

7. Y. Sato, Paramagnetism of molecular compounds: Nature of exchange interactions in organic radical crystals, dissertation, University of Tokyo, May 1969.

8. A.A. Ovchinnikov, Dokl. Acad. Sci. U.S.S.R. **236**, 928 (1977); A.A. Ovchinnikov, Theor. Chim. Acta, Berlin **47**, 297 (1978).

9. Y.U. Korshak, A.A. Ovchinnikov, A.M. Shapiro, T.V. Medvedeva, and V.N. Spektor, Pis'ma Zh. Eksp. Teor. Fiz. **43**, 309 (1986) [English edn. JETP Lett. **43**, 399 (1986)]; Y.U. Korshak, T.V. Medvedeva, A.A. Ovchinnikov, and V.N. Spektor, Nature **326**, 370 (1987).

10. S. Oostra and J.B. Torrance, *Symposium on Horizons in the Properties of Low Dimensional Compounds*, Honolulu, 20 December 1984; J. Torrance, *Proc. Int. Conf. Synthetic Metals, Kyoto* in Synthetic Metals **17**, (1986); J. Torrance, Synthetic Metals **19**, 709 (1987).

11. J.E. Miller, A.J. Epstein, et al., Synthetic Metals **19**, 731 (1987); J.E. Miller and A.J. Epstein, J. Am. Chem. Soc. **109**, 3850 (1987).

12. W.T. Borden and E.R. Davidson, J. Am. Chem. Soc. **99**, 4587 (1977); D.J. Klein, Pure Appl. Chem. **55**, 299 (1983).

13. E. Wasserman, R.W. Murray, W.A. Yager, A.M. Trozzolo, and G. Smolinky, J. Am. Chem. Soc. **89**, 5076 (1967).

14. K. Itoh, Chem. Phys. Lett. **1**, 235 (1967); T. Takui and K. Itoh, Chem. Phys. Lett. **19**, 120 (1973); K. Itoh, Pure Appl. Chem. **50**, 1251 (1978).

15. T. Sugawara, S. Bandow, K. Kimura, H. Iwamura, and K. Itoh, J. Am. Chem. Soc. **106**, 6449 (1984); H. Iwamura, T. Sugawara, K. Itoh, and T. Takui, Mol. Cryst. Liq. Cryst. **125**, 251 (1985); A. Izuoka, S. Murata, T. Sugawara, and H. Iwamura, J. Am. Chem. Soc. **107**, 1786 (1985); T. Sugawara, S. Murata, K. Kimura, H. Iwamura, Y. Sugawara, and H. Iwasaki, J. Am. Chem. Soc. **107**, 5293 (1985); H. Iwamura, Pure Appl. Chem. **58**, 187 (1986).

16. H. Iwamura and K. Itoh, J. Am. Chem. Soc. **108**, 368, 4272 (1986).

17. K. Yamaguchi, H. Fukui, and T. Fueno, Chem. Lett. (Japan) **1986**, 628; K. Yamaguchi, Y. Toyoda, and T. Fueno, Synthetic Metals **19**, 81 (1987).

18. K. Awaga, T. Sugano, and M. Kinoshita, Solid State Comm. **57**, 453 (1986); J. Chem. Phys. **85**, 2211 (1986); Chem. Phys. Lett. **128**, 587 (1986).

Minoru Kinoshita is a full Professor of Chemistry of the Institute for Solid State Physics of the University of Tokyo. He is the author of about 100 papers, mostly on physical chemistry, and the coauthor of the widely cited text Molecular Spectroscopy of the Triplet State, *S.P. McGlynn, T. Azumi, and M. Kinoshita, Prentice Hall, Englewood Cliffs, NJ, 1969.*

Earl Callen, a liaison scientist with the Office of Naval Research Far East, is a Professor of Physics Emeritus of The American University, Washington, DC. His field of interest is condensed matter physics, particularly the magnetic properties of solids. Dr. Callen is the author of 100 publications.

THE COCHIN REGIONAL CENTER OF THE INDIAN NATIONAL INSTITUTE OF OCEANOGRAPHY

Wayne V. Burt

The Cochin Regional Center of the Indian National Institute of Oceanography is responsible for studying the coastal oceanography of the State of Kerala on the southwest coast of India and Indian islands in the Arabian Sea. Marine biologists at the center are engaged in plankton sorting and identification and are also studying coastal and estuarine waters, with special attention being given to environmental pollution and increasing the yield of aquatic resources. Coastal erosion is also being investigated.

INTRODUCTION

Integrated oceanographic research activities began in India in 1962 with the Indian participation in the International Indian Ocean Expedition (IIOE). Cochin was selected to be the main center for shore-based activities of the Indian participation in IIOE.

The Indian Council for Scientific and Industrial Research established a new institute, called the Indian Ocean Biological Center (IOBC), in Cochin. This center soon became the first of its kind in the world. From the beginning it was largely devoted to the study of planktonic organisms in the Arabian Sea, the Indian Ocean, and the Bay of Bengal. With the assistance of experts from many other countries, it soon became world famous for its expertise in sorting and identifying the plankton in the samples taken by the ships of various nations that took part in the International Indian Ocean Expedition.

When the Indian National Institute of Oceanography (NIO), with headquarters in Goa, was established in 1966, IOBC was renamed and became a regional center of NIO. It was given the responsibility of studying the coastal oceanography of the long (550-km), narrow State of Kerala on the southwest coast of India and the Amindivi, Cannanore, Minicoy, and other islands in the Arabian Sea that belong to India.

Dr. N. Khrishan Kutty is the Scientist-in-Charge of the Cochin center. My guide at the center was Dr. Udaya Varma, a physical oceanographer. The center has a staff of 60 persons. About one-third of these are marine biologists engaged in plankton sorting and identification. While study of the plankton of the Indian Ocean region continues to be one of the major activities of the center, the center has diversified its research programs, taking into consideration problems of regional importance. The center has placed considerable importance on estuarine and coastal research because of the vital role the extensive backwaters, estuaries, and coastal regions of Kerala play in developmental activities.

Oceanographic problems of regional importance include coastal zone management and problems associated with the 200-mile exclusive economic zone off the coast of Kerala and around the offlying islands.

MARINE BIOLOGY

A majority of the marine biologists at the center are still engaged in plankton sorting and identification. A number of these sorters have been working at the center for over 20 years and are especially renowned for their ability to identify fish eggs and larvae from commercially important species of fish in the waters around India. A

knowledge of the recruitment potential given by the abundance of eggs and larvae is important in the management of the fisheries as fishery efforts increase and fishing technology improves.

The efforts of sorting fish eggs and larvae at the center may soon receive a shot in the arm. The National Marine Fisheries Service of the U.S. National Atmospheric and Oceanographic Administration is currently endeavoring to set up a joint Indo–U.S. initiative to use PL480 funds (rupees belonging to the United States) to increase the efforts in the study of the distribution of eggs and larvae of commercially important species of fish in the Indian Ocean area.

In addition to the specialized study of plankton, the biologists are, with the help of the chemists, studying coastal and estuarine waters. Special attention is being given to environmental pollution and increasing the yield of aquatic resources. Studies of primary production, benthic and intertidal ecology, fish population dynamics, fish and prawn culture and related physiological problems, and the distribution of pollution on recreational beaches are all underway.

The area off the southwest coast of India is one of the most complex regions of the world's oceans. It is exposed to the extreme fury of the southwest summer monsoon, which causes major coastal erosion problems and changes in underwater topography near shore. These problems will be discussed below. The coastal currents generated by the monsoon winds are accompanied by a complicated system of upwelling. This upwelling and vertical mixing by the strong monsoon winds bring an abundance of nutrients to the surface. This abundance of fertilizers results in a high level of phytoplankton productivity. All levels of the marine food chain are enhanced, from phytoplankton to commercially important food fishes.

COASTAL EROSION

The study of beach erosion along the coast is complicated by the formation, movement, and dissolution of mud banks in the shallow water off the Kerala coast. The changes in the mud banks bring about major changes in the nearshore underwater topography which, in turn, result in transitory temporal changes in wave refraction patterns along the coast. Wave energy is focused at different locations at different times, causing irregular rates of erosion and deposition both in space and time. Usually major erosion takes place during the monsoon seasons, with maximum erosion during July and August. During the process of erosion most of the material appears to be transported offshore and the same materials appear to be deposited back on the beach when an erosion phase is over.

Over a long period of time the beaches appear to be stable unless man interferes. An interesting case in point is the experience with the offshore island of Kavaratti. It is a small sand island once surrounded by a continuous coral reef. The principal axis of the cucumber-shaped island is oriented in a southwest to northeast direction. It is about 7 km long and only 1/2 to 1 km wide. During the southwest monsoon, sand is moved from the southwestern tip of the island to the northeastern tip. After the monsoon is over the littoral currents slowly transport the sand back to its premonsoon distribution. A shipping channel was cut through the coral reef near the northeastern tip of the island. There is evidence that sand is lost through the channel during the monsoon and not recovered. If this process continues long enough the island could slowly disappear.

All the problems of beach protection are compounded by the variability of the wave forces acting on the beach at any given time and place.

COASTAL POLLUTION

Except for a few large inland cities, the coastal zone is the most thickly populated region of the Indian subcontinent, especially along the southwest coast of Kerala. A decade-long, year-round study has recently been completed of the pollution on the beaches and in the surfzone in the environment of 10 bays and 20 beaches that are located between the southern tip of India up the west coast to the northern tip of Kerala. The rationale for the study was the importance of the beaches for tourism, which is a major industry in the area. The country needs more beaches that are safe for tourists. The results of the study showed that the shores and nearshore waters of bays where fishing villages are located are as much as an order of magnitude more polluted with human waste than the nearby beaches and inshore waters. Also, even on the cleaner beaches, the amount of pollution increases markedly at the start of the monsoon rainy season when local runoff increases directly over the beaches, washing the pollution from the land to the sea.

One of the novel recommendations resulting from the study was that inhabitants of the coast, especially those living under unhygienic conditions, should be moved back from the coast. There should be an uninhabited 1/2-km-wide strip along the beach with free access to the sea.

The center is currently housed in two old mansions in the center of the city of Ernaculum, the only major city of Cochin. The State has given the center a place on the water to build a new laboratory, which has not materialized yet. The center is, however, moving to newer and larger quarters within the city.

The address of the center is: National Institute of Oceanography, Regional Centre, Pullepady Cross Road, P.O. No. 1913, Cochin - 530 017.

Wayne V. Burt received his Ph.D. from Scripps Institute of Oceanography in 1952 (UCLA). Dr. Burt was Science Attache for Oceanography and Meteorology in the American Embassy in New Delhi, India, from October 1986 to April 1987. Previously, he was a professor at Oregon State University and served as a liaison scientist of oceanography and meteorology for the Office of Naval Research, London, from 1979 to 1980. Dr. Burt's current interest is in air-sea interaction.

RECENT RESEARCH ON SiC WHISKER–REINFORCED CERAMIC COMPOSITES IN JAPAN

Shigehiko Yamada

Research on SiC whisker–reinforced ceramic composites has gained momentum in the past few years since the development of an industrial process for obtaining the whiskers. In this article recent activities in this field of ceramic composites are summarized. Composite matrices of glass and glass–ceramics, alumina, zirconia, silicon nitride, silicon carbide, mullite, spinel, and aluminum nitride are discussed.

INTRODUCTION

About 20 years ago, Krochmal of the Air Force Materials Laboratory (AFML) reviewed and assessed fiber–reinforced ceramics and their potential (Ref 1) even before carbon fiber was industrialized. No suitable material was found, although there was a wide variety of reinforcers and matrices. About 5 years ago, when silicon carbide whiskers (SiC_W) were introduced as an industrial material in Japan, researchers at the Osaka Government Industrial Research Institute (GIRI) developed a SiC_W–reinforced Si_3N_4, which can be regarded as pioneering work in this field (Ref 2,3). Watts reported that research and development (R&D) work on SiC_W was rekindled by the discovery of an industrial process for obtaining the whiskers (Ref 4). Since then, particularly in the past 2 to 3 years, quite a few papers on various kinds of matrices were published. New products of this type of composite using Al_2O_3 and SiO_2 have appeared in industry, which may suggest the importance of ceramic composites. In this article recent activities in this field in Japan are summarized in as much detail as possible, with foreign research mentioned for reference only.

GLASS AND GLASS–CERAMIC MATRICES

Sakamoto and Ito (Ref 5) glassified $25MgO–21Al_2O_3–54SiO_2$ (wt.) by heating at 1,550 °C for 3 hours, followed by pulverizing to 2 μm by ball–milling and mixing with 0 to 50 percent of SiC_W in the wet state. Hot–pressing at 880 and 1,180 °C for 1 hour at 340 MPa was carried out. Figure 1 shows the results, where a typical improvement in the SiC_W content at up to 30 wt. % can be seen. Higher concentrations of SiC_W (40 to 50 wt. %) made the densification difficult, giving lower strength and K_{IC} values which are, however, still higher than those of the matrix itself.

Oka et al. (Ref 6) and Yamada (Ref 7) prepared SiC_W in situ with excess SiO_2 mixed with a limited amount of carbon black so that a homogeneous mixture could be made. Hot–pressing of the mixture was not easy because of the chemical reaction between SiC_W and SiO_2 and also because of the big difference in their coefficient of thermal expansion (CTE), but a 40– by 50– by 5–mm specimen was successfully obtained. Figure 2 shows the prepared SiC_W in situ in SiO_2 particles, like a spider's web over the particles.

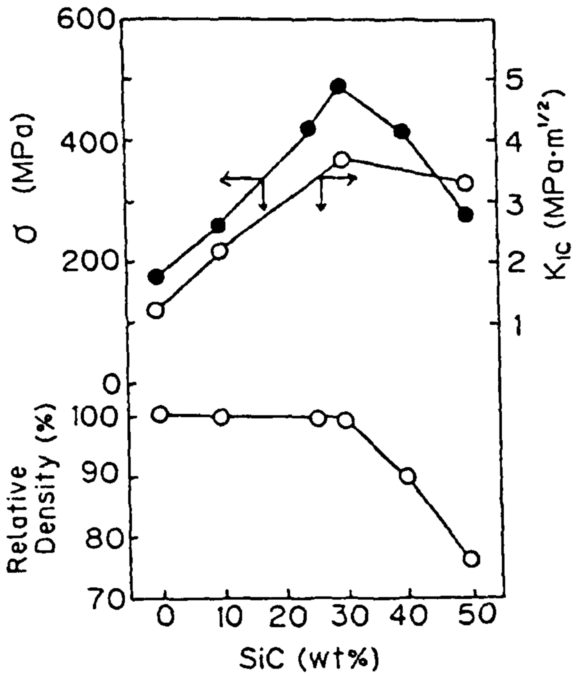


Figure 1. Strength, fracture toughness, and relative density of the composite (from Ref 5).

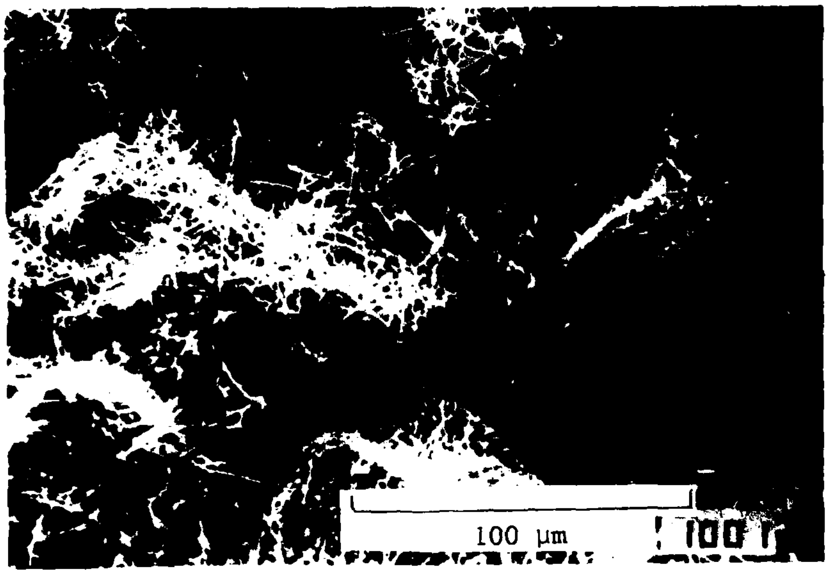


Figure 2. SiC_w prepared in situ in SiO_2 (from Ref 6).

In experiments conducted by Kagawa et al. (Ref 8,9), SiC_w and Si_3N_{4w} were mixed with 40-percent colloidal silica, which was added to silica-glass powder and sintered. Fifteen vol % of Si_3N_{4w}-reinforced CGW# 7740 gave a K_{IC} of 2.5 MPa $m^{1/2}$ in comparison with a K_{IC} of about 1 MPa $m^{1/2}$ for the matrix itself. A difference in acoustic emission (AE) waves was observed as illustrated in Figure 3, which was obtained by an indentation test. This difference may suggest that the improvement in K_{IC} was due to the formation of microcracks, which are assumed to occur by the increase in event accounts.

Researchers from Ceramiques Techniques Desmarquest (Ref 10) developed a composite SiC_w/SiO_2 as an industrial product, continuously prepared in a plant, for the exhaust liners of cars (Ref 11). Gadkaree and Chyung (Ref 12) investigated several kinds of glass and glass-ceramic matrices with SiC_w. Layden and Prewo (Ref 13) experimented with alumino- and boro-silicates.

ALUMINA MATRIX

Figure 4 shows the reinforcing effect of SiC in comparison with mullite and zirconia matrices. The variance of strength decreased as the SiC_w content increased, perhaps because the sintering (hot-pressing) process had a restraining effect on particulate growth. However, no improvement of strength could be observed, differing from the other matrices (Ref 14). Pull-out of SiC_w was observed only in the case of alumina. Yasuda et al. (Ref 15) coated the whiskers with carbon using the chemical vapor deposition (CVD) procedure to clarify the pull-out effect.

In experiments performed by Inoue et al. (Ref 16), a mixture of Al_2O_3, partially stabilized zirconia (PSZ), and SiC_w (70:15:15 vol %) was ball-milled; bending strength as high as 1,181 MPa (n = 20) was obtained. K_{IC}, as well as high temperature strength (1,200 °C), was also determined. They concluded that the instability of $Zn0_2$ in the phase transformation matched the stress field.

In other experiments, Inoue and Nonaka (Ref 17) investigated the difference in toughening mechanisms by using two kinds of ZnO_2 crystals. With tetragonal zirconia polycrystals (TZP), which retained a tetragonal structure at room temperature, tensile stress was formed by a difference in CTE (α-SiC_w < α-$Zr0_2$) in the matrix phase, giving the pull-out effect of the whiskers. On the other hand, ZrO_2 without stabilizers transformed to a monoclinic structure at room temperature. As a result, the flexural strength of the TZP was 1,191 MPa, while the value for $Zr0_2$ was only 651 MPa. The K_{IC} values were 8.43 and 6.57 MPa $m^{1/2}$, respectively. The maximum strength of 1,437 MPa was obtained by using heat treatment.

At the 1987 New Materials Exhibition in Tokyo, in May 1987, Riken Company presented its new product, SiC_w-reinforced alumina containing zirconia. Sumitomo Cement Company also presented a SiC_w/Al_2O_3 composite at the exhibition, but no details were available.

Figures 5 and 6 show the change in flexural strength and the change in fracture toughness, respectively, as a function of volume fraction, where pull-out of the whiskers was observed (Ref 18).

Figure 7 shows the results of research by Matsubara et al. (Ref 19). The specimens were hot-pressed (H.P.) at 1,850 and 1,900 °C for 30 minutes at 20 MPa. The K_{IC} values at 1,900 °C were lower because of the lack of pull-out, which was due to the higher sintering temperature; this may suggest the importance of the pull-out effect.

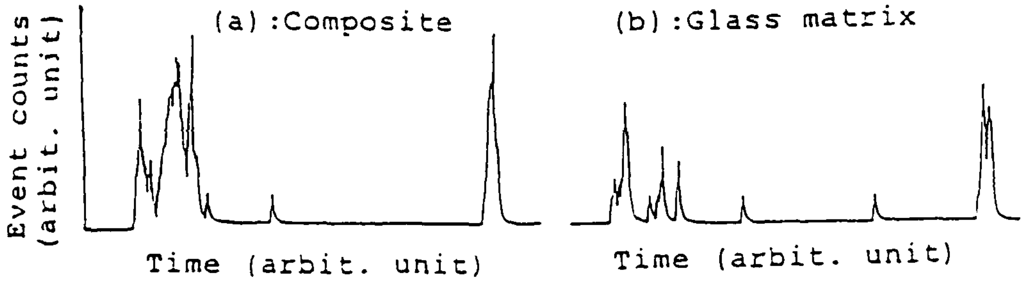


Figure 3. Detected acoustic emission events during the loading/unloading process of the Vicker's indentation test (from Ref 9; reprinted with permission from the Iron and Steel Institute of Japan).

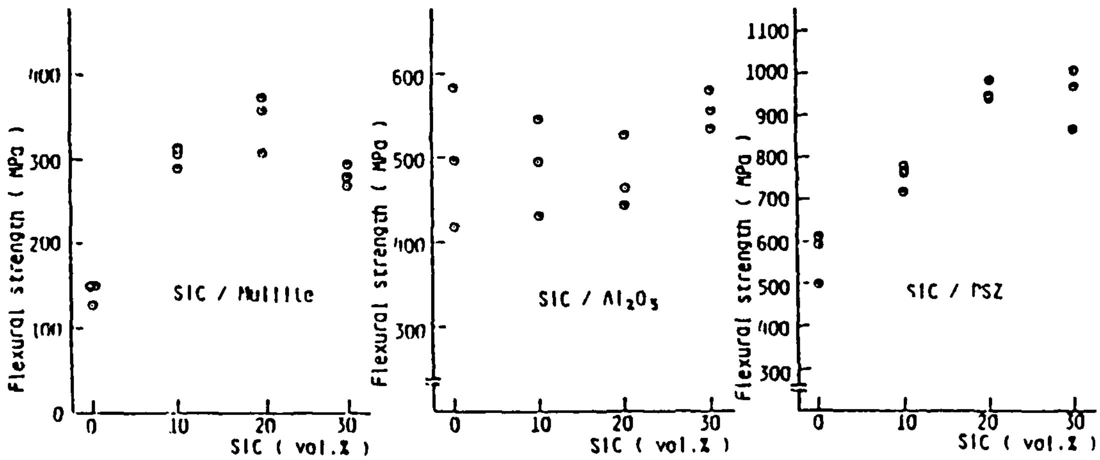


Figure 4. Flexural strength of hot-pressed SiC whisker/oxide ceramic composites at room temperature (from Ref 14).

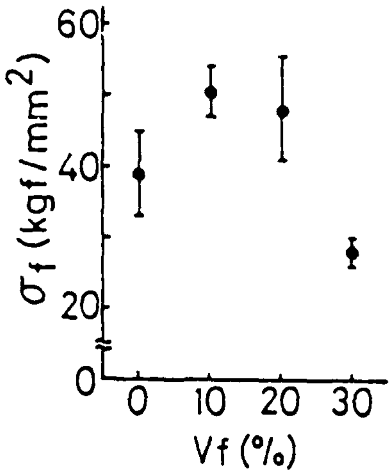


Figure 5. Change in flexural strength as a function of volume fraction, V_f, of SiC_w (from Ref 18).

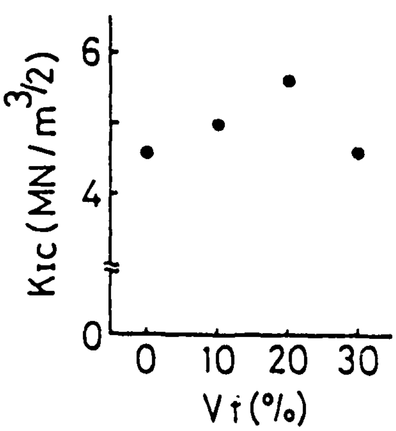


Figure 6. Change in fracture toughness, K_{IC}, as a function of V_f of SiC_w (from Ref 18).

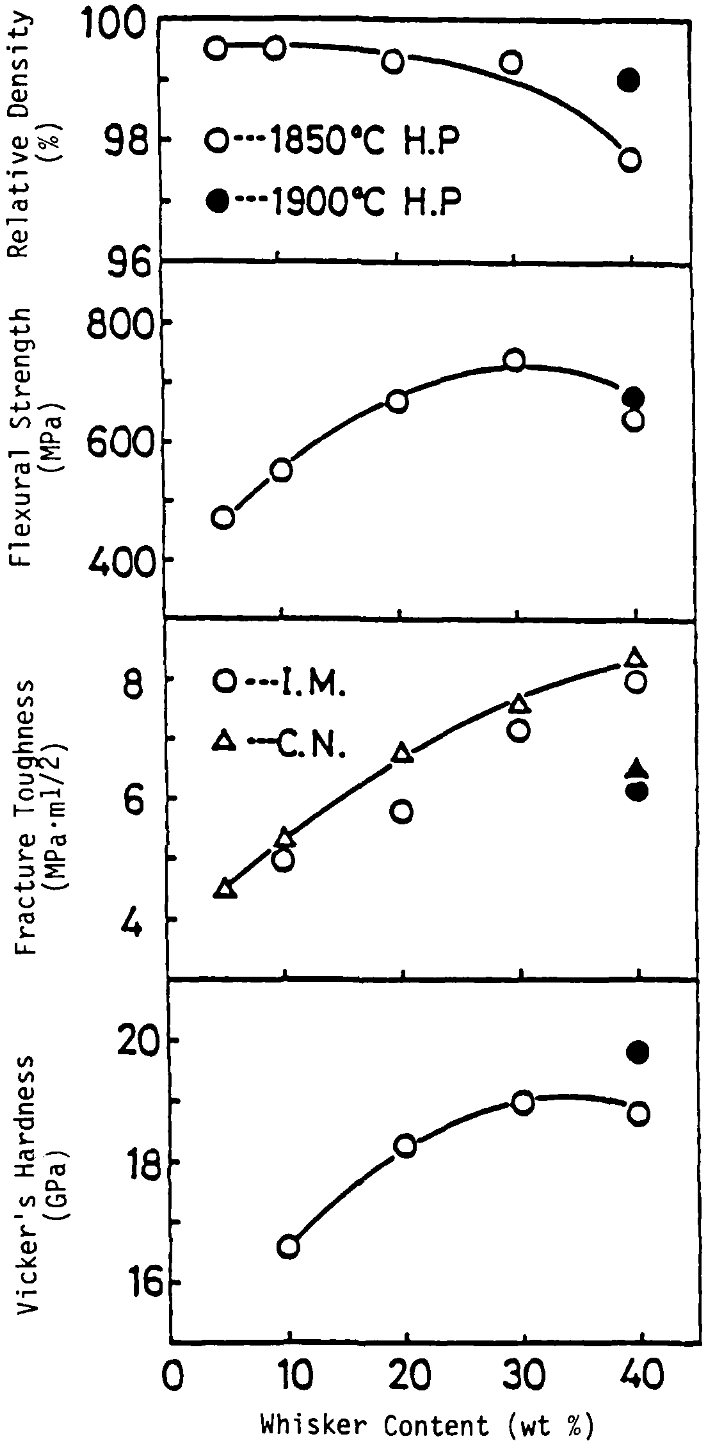


Figure 7. Change in physical properties as a function of SiC_w content (from Ref 19).

Iwamoto et al. (Ref 20) added 1.5 and 3.0 percent of SiC_w and Si_3N_{4w} to Al_2O_3 for plasma spraying to toughen the formed film. Figure 8 shows an increase in the number of cycles until the film was broken by a thermal shock between 1,373 K and room temperature (duration = 60 seconds) with water spray. Figure 9 shows another improvement obtained by a falling down test of a 110-gram steel ball, dropped from a height of 825 mm. A maximum increase of four times the number of ball impacts can be seen.

Becher and Wei's work (Ref 21,22) is now very famous, and Becher recently collaborated with Tiegs (Ref 23) on further research. Other work of interest includes Homeny et al. (Ref 24), Porter et al. (Ref 25), and Chokshi and Porter (Ref 26).

ZIRCONIA MATRIX

As illustrated in Figure 4, PSZ was compared with mullite and alumina matrices (Ref 14). Further work by Yasuda et al. (Ref 27) is summarized in Figures 10 and 11. It should be noted that higher strength was observed at elevated temperatures in the 30-vol % SiC_w specimen (Figure 11) than at room temperature (Figure 10).

As shown in Figures 12 and 13, at sintering temperatures of 1,400 and 1,500 °C, no increase in strength or fracture toughness could be observed due to insufficient densification (Ref 28).

In research conducted by Akimune et al. (Ref 29), the relationship between the microstructure determined by both scanning electron microscopy (SEM) and transmission electron microscopy (TEM) and the mechanical properties of SiC_w/TZP was investigated and Figure 14 was obtained. The Weibull coefficient increased as the SiC_w content increased, which may be due to the uniformity of critical size. The increase in K_{IC} related to the tetragonal-monoclinic transformation by TEM was also discussed. In the case of 30 vol % of SiC_w, crack deflection was considered to contribute to the toughening rather than the transformation effect.

Miyagawa et al. (Ref 30) obtained some interesting results during their research, as illustrated in Figures 15 and 16. The lower value of strength, 30 V_f (%), at room temperature is based on the higher porosity of the composite.

The work of Claussen et al. (Ref 31) is well known and was carried out at almost the same time as initial research in Japan (Ref 14). The author learned that Claussen used a new mixer, called a tumbling mixer, which will be mentioned later.

SILICON NITRIDE MATRIX

As described in the INTRODUCTION section, this type of composite was created by a Japanese research group (Ref 2,3) in 1982. In 1986 and 1987, several relevant papers were presented.

At the beginning stage, SiC_w were prepared by Tamari and others in their laboratory by CVD. At the same time, an industrial version of SiC_w was prepared in a pilot plant in which the author was employed. Tamari and Ueno proved that there was no difference between the SiC_w prepared experimentally or industrially, making it possible for the manufacturer to market SiC_w as an industrial product. In addition to the change in mechanical properties by reinforcing, they found:

- Weibull coefficient was high, over 24, indicating higher reliability of the composite.

- Wear property was improved, as shown in Figure 17 (Ref 32).

- Electrical discharge machining of the Si_3N_4 composite became possible because of the electrical conductivity of the SiC component (Ref 33).

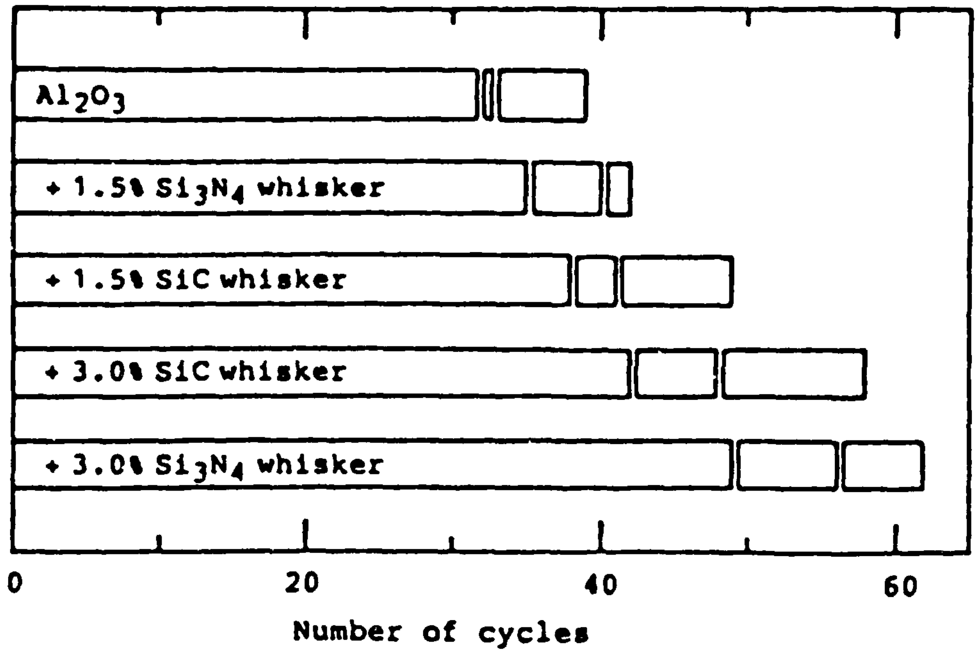


Figure 8. Results of thermal shock test on the sprayed film (from Ref 20).

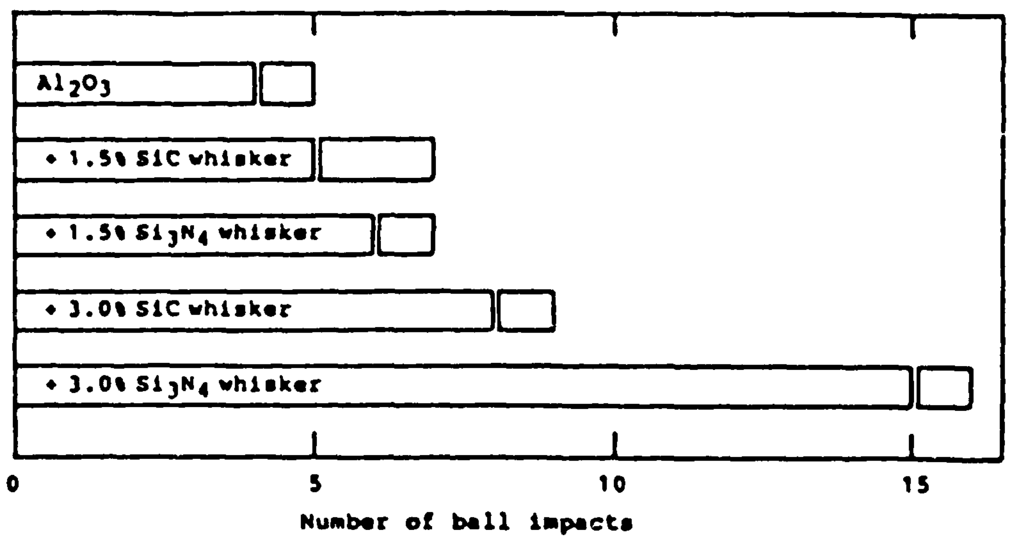


Figure 9. Results of falling down test on the sprayed film (from Ref 20).

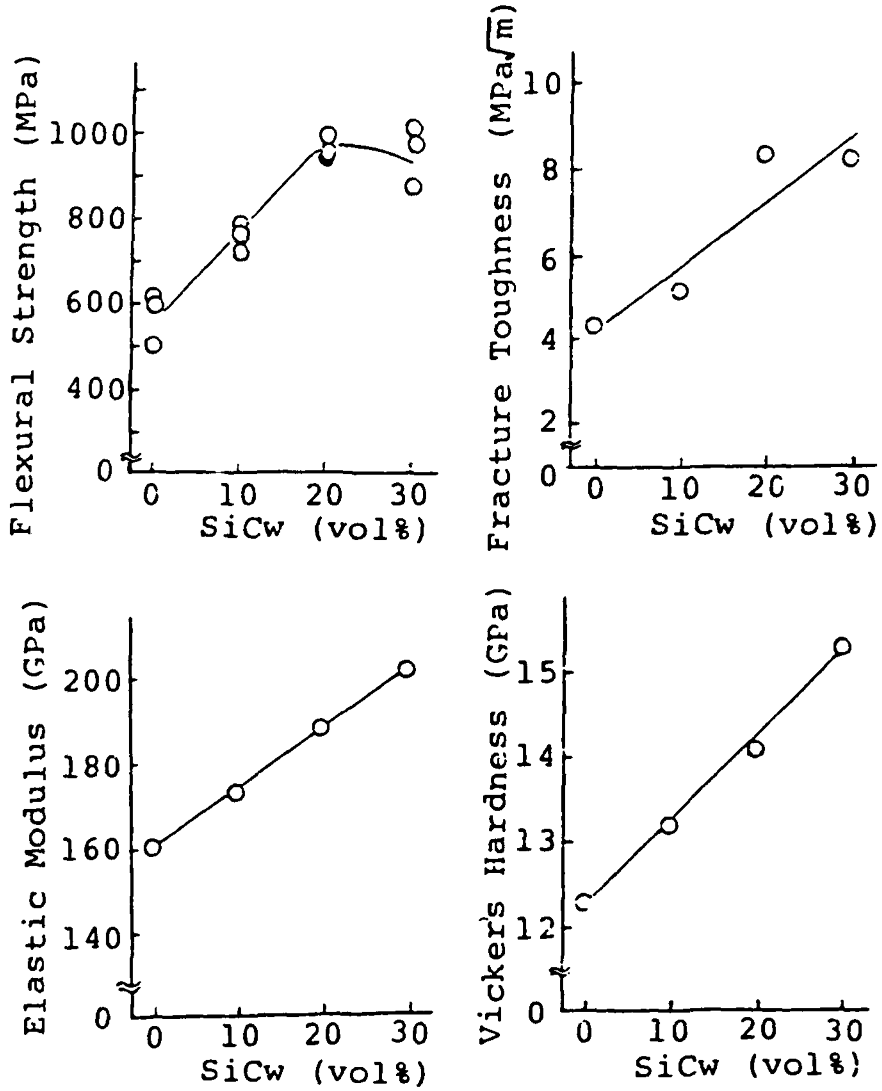


Figure 10. Mechanical properties of SiC_W/PSZ composites at room temperature (from Ref 15).

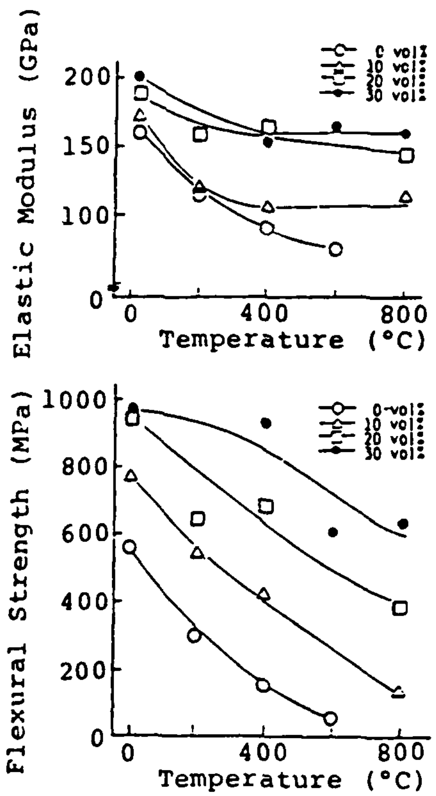


Figure 11. Elastic modulus and flexural strength of SiC_W/PSZ composites at elevated temperature (from Ref 15).

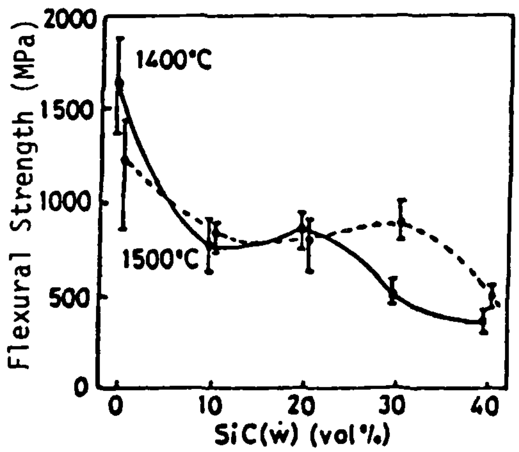


Figure 12. Change in flexural strength (from Ref 28).

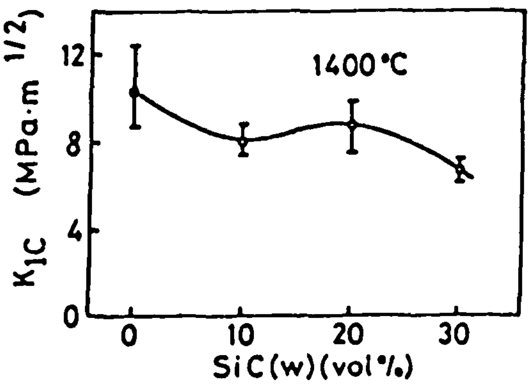


Figure 13. Change in fracture toughness (from Ref 28).

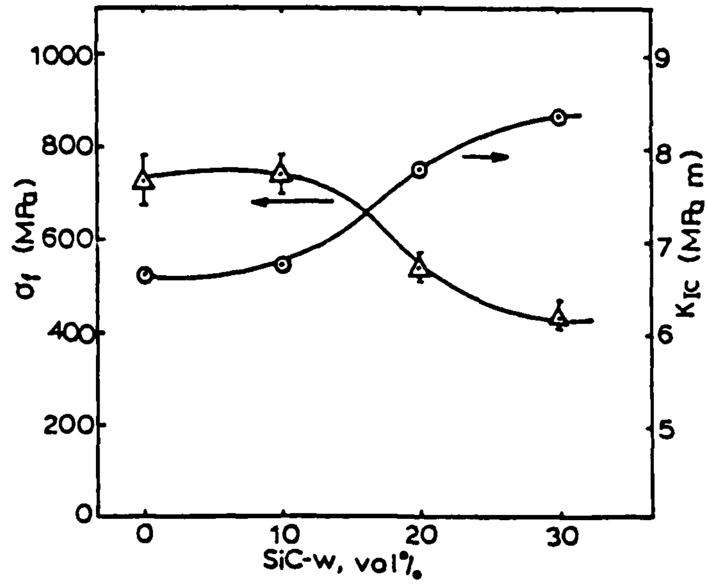


Figure 14. Flexural strength and fracture toughness of the composite (from Ref 29).

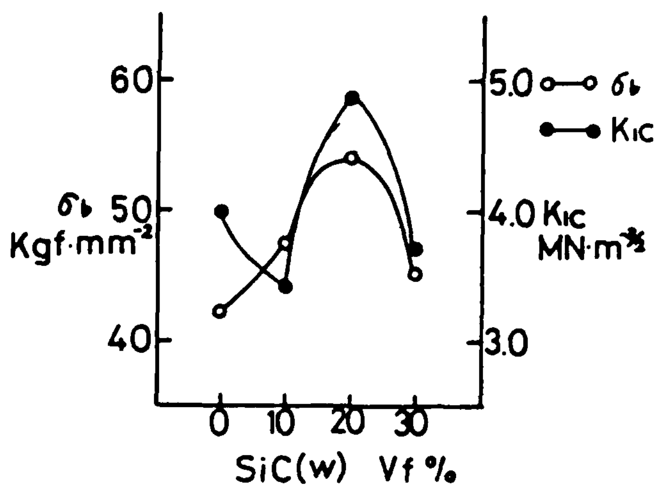


Figure 15. Flexural strength and fracture toughness at room temperature (from Ref 30).

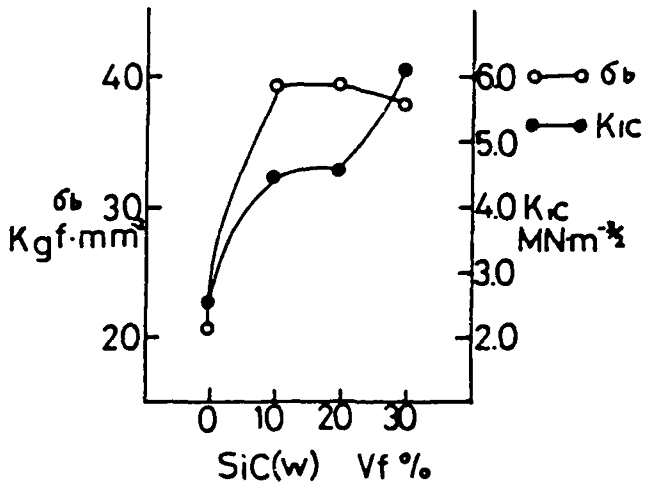


Figure 16. Flexural strength and fracture toughness at 1,300 °C (from Ref 30).

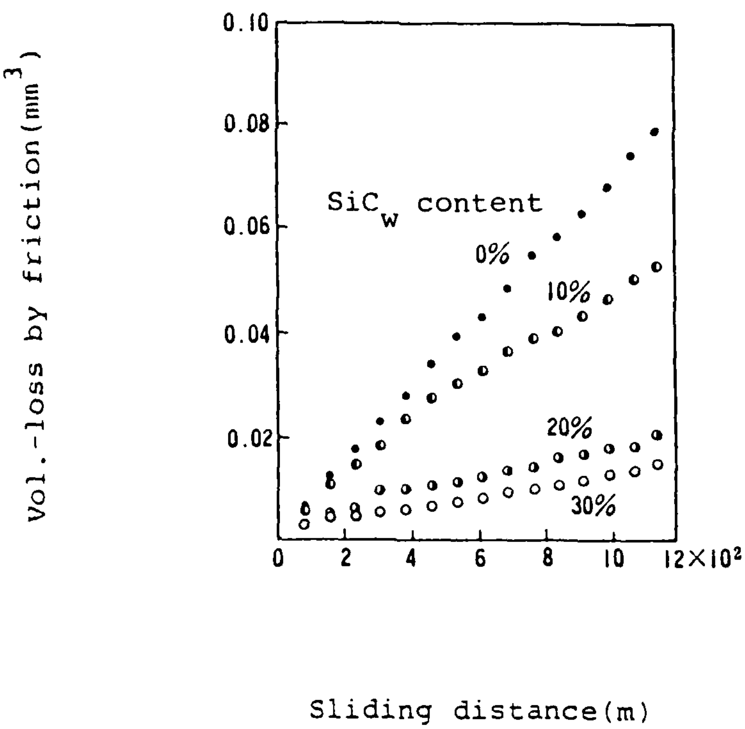


Figure 17. A wear property of SiC_w/Si_3N_4 (from Ref 32).

Further work on sintering in a normal atmosphere, aimed at obtaining complicated shapes and larger sizes, was carried out, resulting in Figures 18 and 19. Larger amounts of sintering aids (Y_2O_3 and La_2O_3) were needed for this application than for hot-pressing (Ref 34,35).

Thermal properties, such as thermal shock resistivity, thermal conductivity, and thermal expansion up to 1,400 °C, as well as resistivity versus air oxidation at 1,300 and 1,400 °C for 24 hours were also investigated (Ref 36,37). Figure 20 shows an example of K_{IC}. By using SEM, it was concluded that thicker whiskers were desired, although a length of only 10 µm was enough (Ref 38).

The first successful structural ceramics application of Si_3N_4 for a turbocharger in Japan is well known (Ref 11), and efforts to toughen this composite will be made enthusiastically.

In other research by Kandori et al. (Ref 39), an injection molding process was applied, giving a preferred orientation of SiC_w in Si_3N_4, although the SiC_w content was as low as 10 percent. Hot isostatic pressing (HIPing) was also carried out; however, as seen in Figure 21, the flexural strength had improved even before HIPing, perhaps because of the orientation.

Yonezawa et al. (Ref 40) used the sintering aids Y_2O_3 and Al_2O_3 for hot-pressing. Table 1 summarizes the results. Figure 22 illustrates the relationship between temperature and strength of the specimens listed in Table 2 (Ref 41).

Without any sintering aids, the silicon nitride was cold isostatically pressed (CIPed) under 200 MPa, calcinated at 1,200 °C for 2 hours under 10^{-5} Torr, and then HIPed under 180 MPa at 1,900 °C for 3 hours. The results are summarized and shown in Figures 23 to 25 (Ref 42).

As mentioned in the GLASS AND GLASS-CERAMIC MATRICES section (see Figure 2), in-situ preparation in Si_3N_4 matrix powder was carried out to make a homogeneous mixture of solids having different sizes and shapes as SiC_w and Si_3N_4 fine powder. In comparison with regular physical mixing, this process, called chemical mixing, produced the results illustrated in Figure 26. A tumbling mixer was used for effective deagglomeration (Ref 43,44). Further research is being conducted from an economical standpoint.

In research activities outside of Japan, Shalek et al. (Ref 45) are concerned with fracture toughness and its surface energy as a function of SiC_w content up to 40 vol %. Lundberg et al. (Ref 46) investigated HIPed SiC_w/Si_3N_4 composites. Buljan et al. (Ref 47) clarified the relationship between density and hot-pressing time as well as K_{IC} and modulus of rupture (MOR) as functions of SiC_w content.

SILICON CARBIDE MATRIX

In this area, only the work of Sodeoka et al. (Ref 48,49) has been published. Figures 27 to 29 show the results of this research. Lower values of toughness and strength at SiC_w contents over 30 percent are considered to be due to crystal growth on the surface of the whiskers, although the density is high enough, as observed in Figure 29.

MULLITE MATRIX

In addition to their earlier research, as shown in Figure 4 (Ref 14), Kimura et al. (Ref 50) reported other work on the sol-gel method by using ortho-methyl-silicate and aluminum sec-butoxide. At almost the same time, Wei and Becher (Ref 22) improved K_{IC} from 2.2 to 4.6 MPa $m^{1/2}$ in comparison with alumina matrix reinforced by SiC_w.

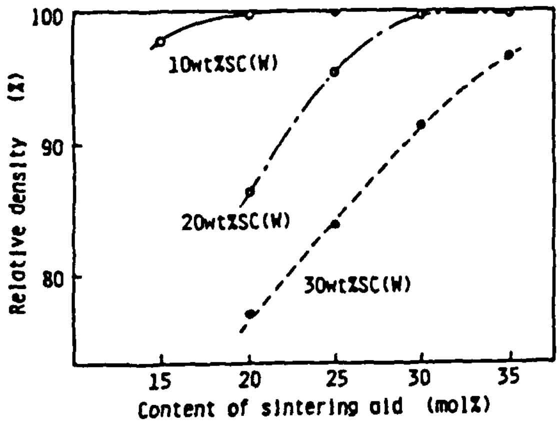


Figure 18. Relationship between SiC_w content and amount of sintering aid (from Ref 34).

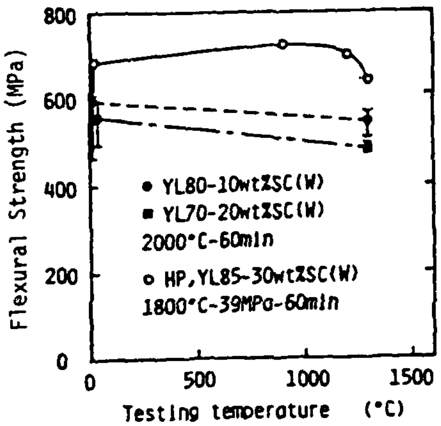


Figure 19. Change in strength versus temperature (from Ref 34).

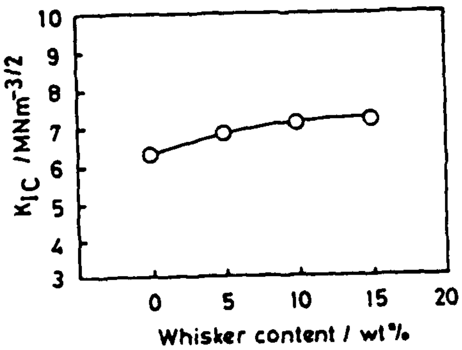


Figure 20. Variation of K_{IC} with the whisker content. Data obtained from chevron notch method (from Ref 38).

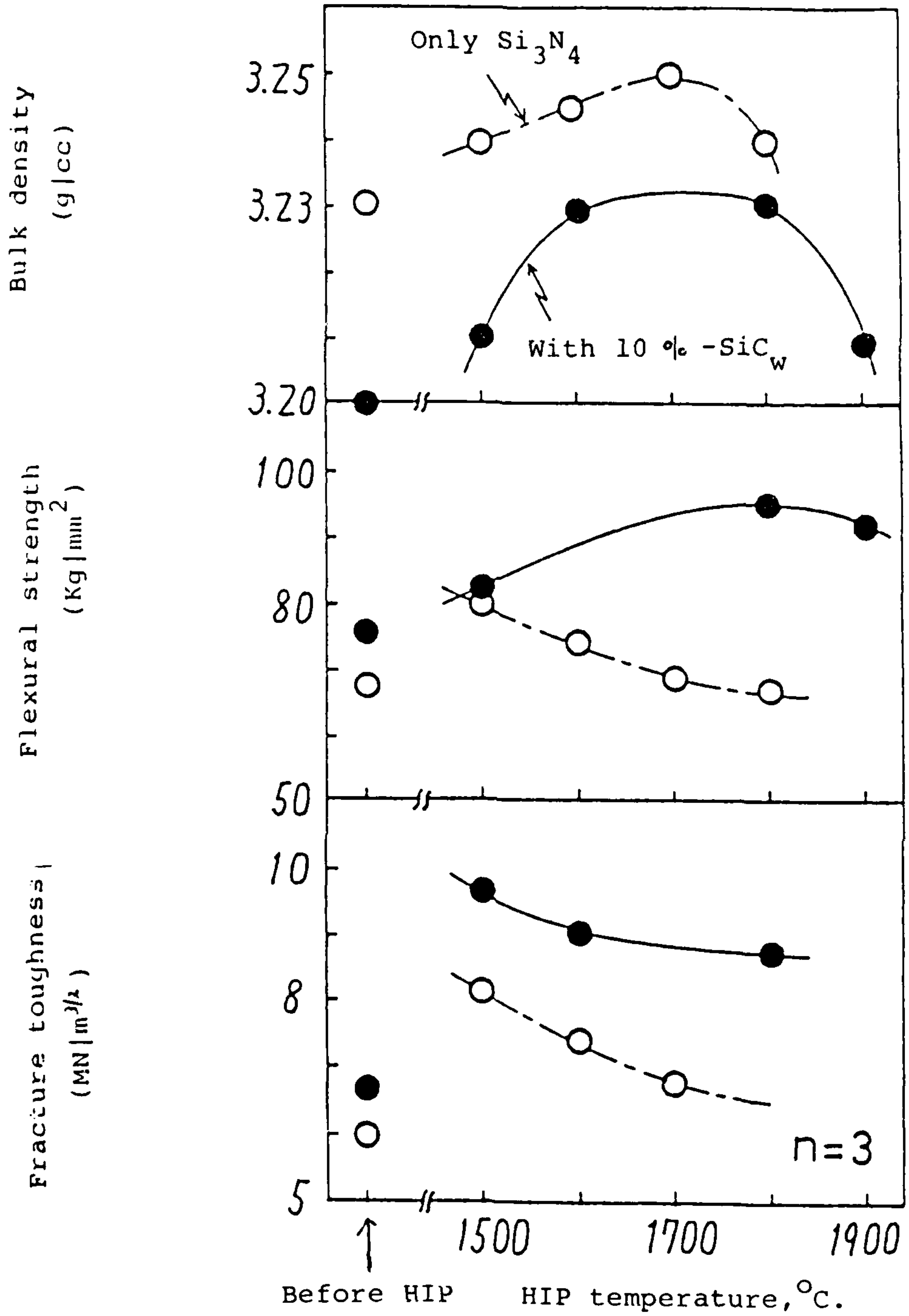


Figure 21. Bulk density, strength, and fracture toughness as a function of HIP temperature (from Ref 39).

Table 1. Several Properties of Hot-Pressed Materials

Material	Bulk Density (g/cm^3)	Strength at Room Temperature (kg/mm^2)	K_{IC} ($MPa\ m^{1/2}$)
a. Si_3N_4 + 5% Y_2O_3 + 2% Al_2O_3	3.26	102	9.0
b. a + 40% SiC whiskers	2.87	84	7.5
c. b + 5% Y_2O_3	2.86	83	7.3
d. b + 5% Al_2O_3	3.22	121	8.8
e. b + 5% MgO	3.22	118	8.3
f. b + 5% AlN	3.12	86	8.3

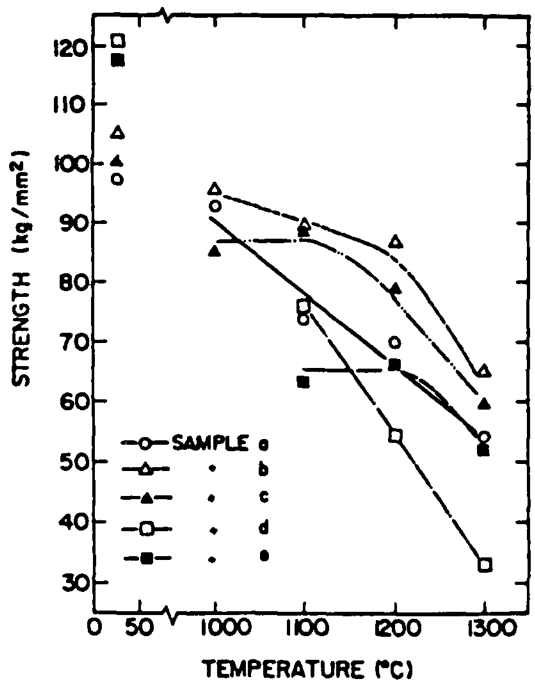


Figure 22. Temperature dependency of flexural strength (from Ref 41).

Table 2. Composition and Bulk Density of Sintered Specimens in Figure 22

Sample	Composition	Bulk Density (g/cm^3)
a	Si_3N_4 + 5% Y_2O_3 + 2% Al_2O_3	3.26
b	a + 20% whisker	3.21
c	a + 20% whisker + 5% MgO	3.23
d	a + 40% whisker + 5% Al_2O_3	3.22
e	a + 40% whisker + 5% MgO	3.22

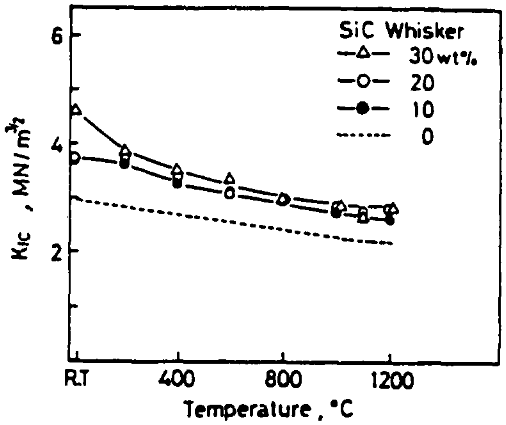


Figure 23. Temperature dependency of fracture toughness (from Ref 42).

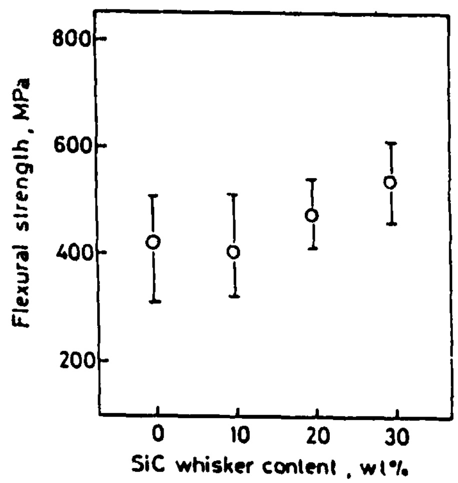


Figure 24. Flexural strength as a function of SiC_w content (from Ref 42).

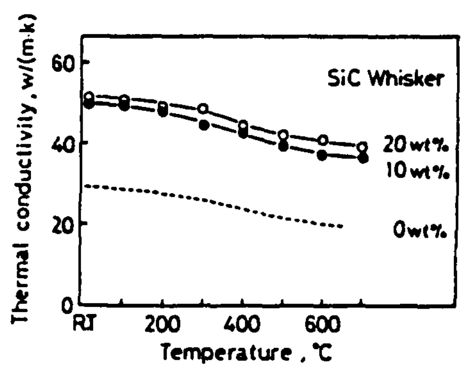


Figure 25. Temperature dependency of thermal conductivity (from Ref 42).

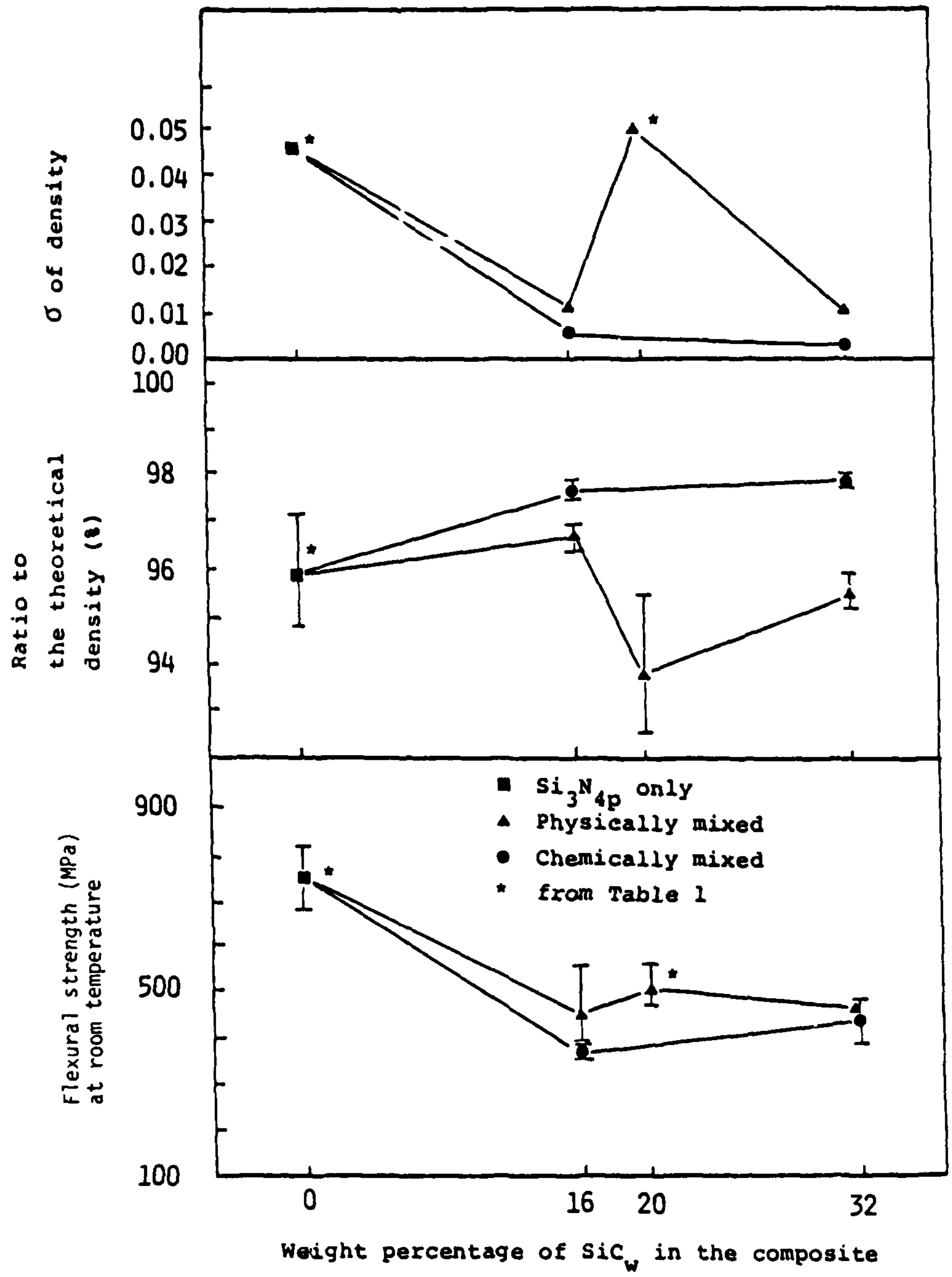


Figure 26. Density, its standard deviation, and bending strength of hot-pressed pieces derived from both mixing procedures using Y_2O_3 + La_2O_3 as sintering aids (from Ref 44).

Note: A big diffe:ence in pore size distribution of the compressed ,reen bodies of both mixing procedures was also made clear.

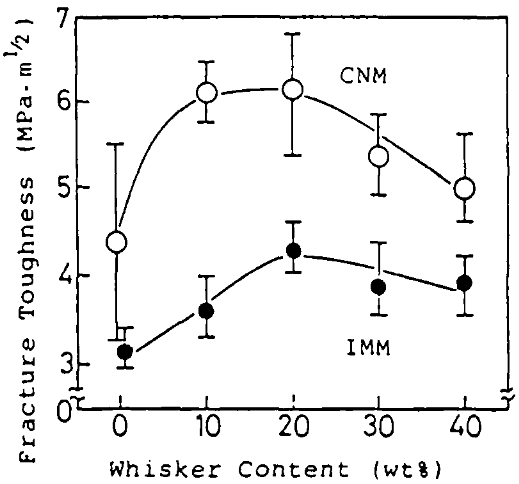


Figure 27. K_{IC} and SiC_W content (CN method: n = 4; IM method: n = 10) (from Ref 49).

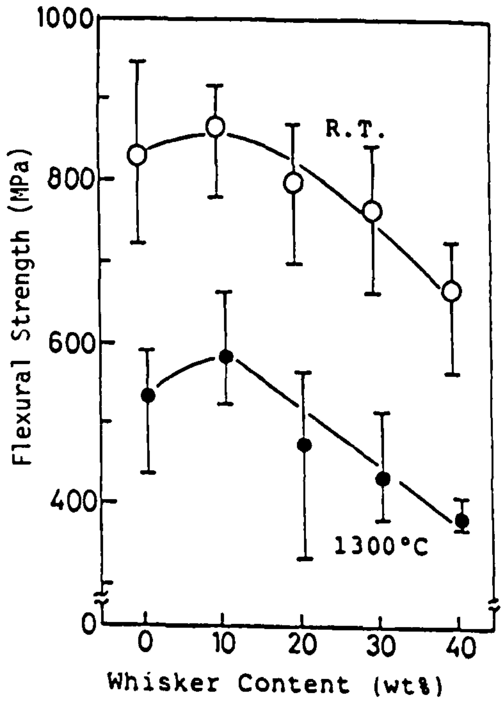


Figure 28. Flexural strength and SiC_W content (R.T.: n = 12; 1,300 ^{o}C: n = 8) (from Ref 49).

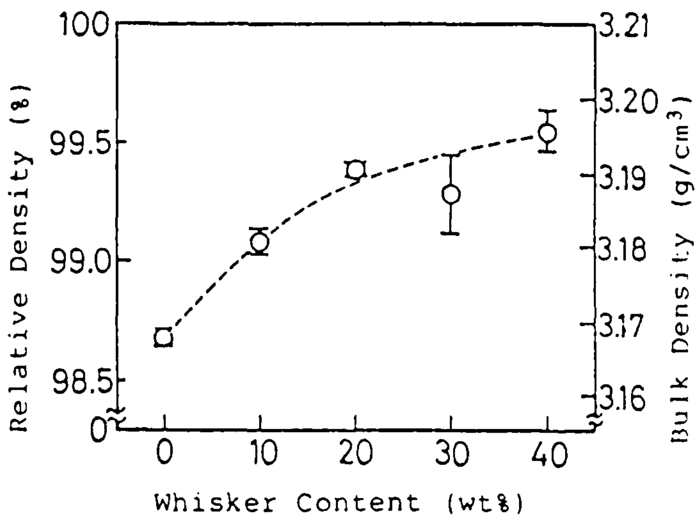


Figure 29. Density and SiC_W content (CN method: n = 4; IM method: n = 10) (from Ref 49).

Figures 30 and 31 show the results obtained by Kanzaki et al. (Ref 51). Figure 30 shows the positive effect of the reinforcement, whereas the effect at higher temperatures was found to be negative as shown in Figure 31.

Recently, Kamiaka et al. (Ref 52) presented data, summarized in Figures 32 to 34, showing the sintered SiC/mullite composite under normal pressure in comparison with the hot-pressed results in Figures 30 and 31. The relationship between the results in Figures 32 to 34 and the observation of fractured surfaces by SEM was also discussed.

SPINEL MATRIX

Nakano et al. (Ref 53) reported a flexural strength (214 MPa) 1.5 times higher for hot-pressed spinel containing 20 vol % of SiC_w. The results, shown in Figures 35 and 36 and obtained in collaboration with Kato, Hayashi, and others, are in comparison with alumina matrix composites (Ref 18). Less porosity (as low as 0.2 percent) was obtained with spinel derivatives than with alumina derivatives. Inoue et al. (Ref 54) and Claussen and Petzow (Ref 55) also performed research in this area.

CORDIERITE MATRIX

No research has been performed in Japan, although Claussen and Petzow (Ref 55) published their results.

ALUMINUM NITRIDE MATRIX

Nishida et al. (Ref 56) reported the results shown in Table 3 and in Figure 37. Hot-pressing was carried out at 1,800 °C for 30 minutes under 200 kgf/cm^2 after ball-milling. Table 3 suggests that the addition of a small amount of Y_2O_3 and SiO_2 enabled the densification. The reinforcing effect shown in Figure 37 was a result of the greater pull-out of SiC_w observed at higher temperatures by SEM of the fracture surfaces. According to research by them on a MgO matrix, the reinforcing effect was not so high, probably because of the smaller difference in the modulus of each component, AlN and SiC_w, even at high temperatures (Ref 57).

MOLYBDENUM DISILICIDE ($MoSi_2$) MATRIX

Japanese research efforts in this area have not been published. The research by Gac and Petrovic (Ref 58) concerned an improvement in strength and toughness, leading to the conclusion that this type of composite is a feasible one.

CONCLUSION

About one-third of the literature on SiC whisker-reinforced ceramic composites has been published since the beginning of 1987, which suggests renewed interest in the feasibility of using these composites in structural ceramic applications. Professor T. Ishii, of Tokyo University, described the history of world technology as a long stream of technological civilization, originating in the ancient times and migrating through the Mediterranean civilization, to the Renaissance, to the "Century of America," and finally arriving at the "Age of the Pacific Ocean" (Ref 59). Applying his concept of "from the Atlantic to the Pacific" to the study of ceramic composites, we must make the effort to further develop this high-tech material by steadily collaborating with American research groups.

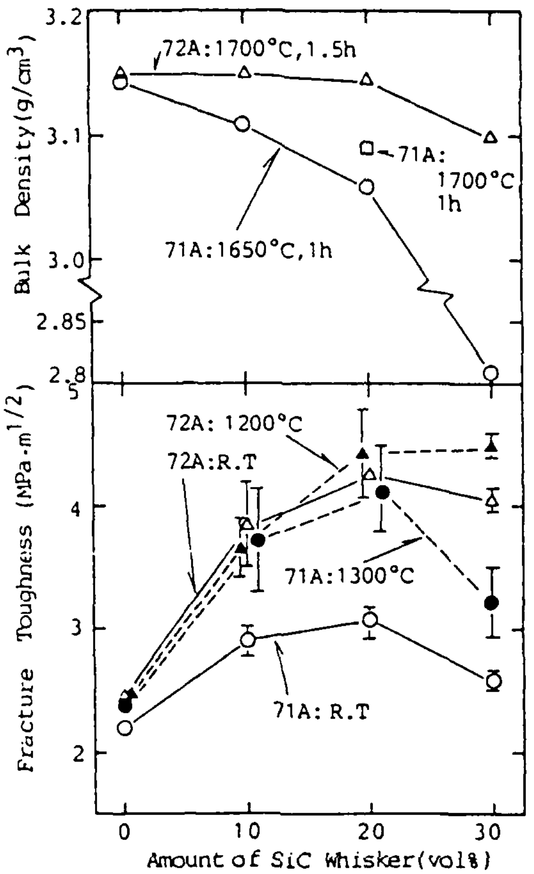


Figure 30. Density and fracture toughness versus SiC_w content (from Ref 51).

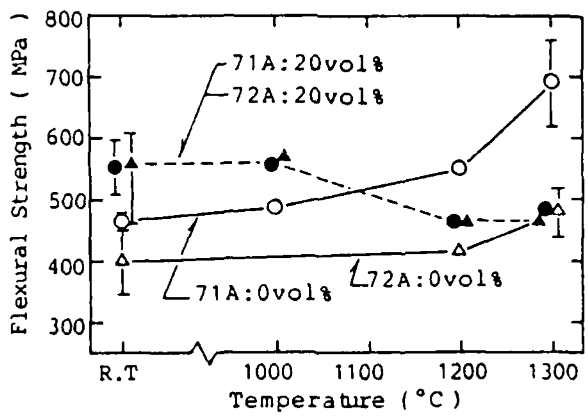


Figure 31. Change in flexural strength at higher temperatures (from Ref 51).

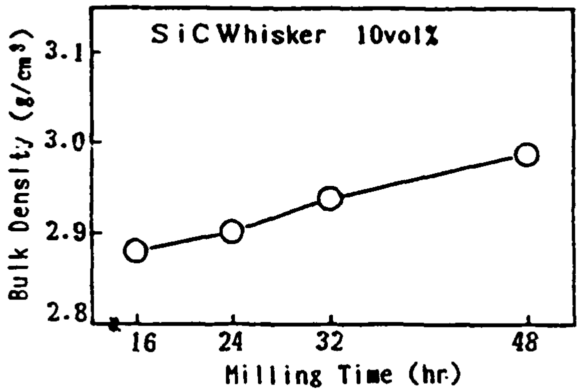
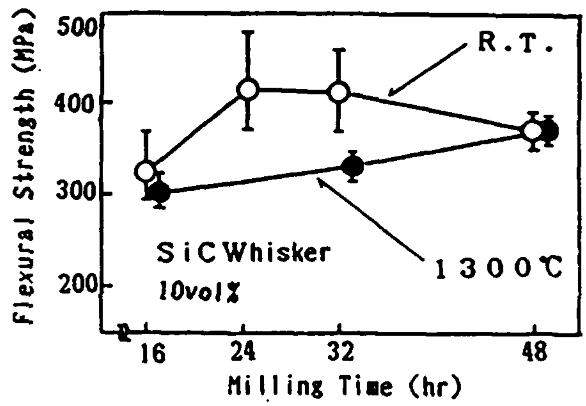


Figure 32. Bulk density versus milling time (from Ref 52).

Figure 33. Flexural strength versus milling time (from Ref 52).



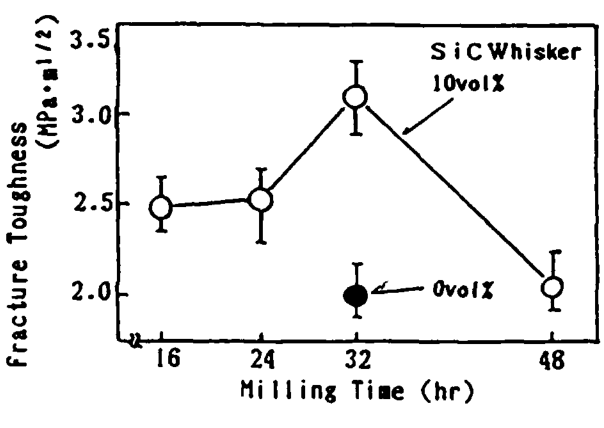


Figure 34. Fracture toughness versus milling time (from Ref 53).

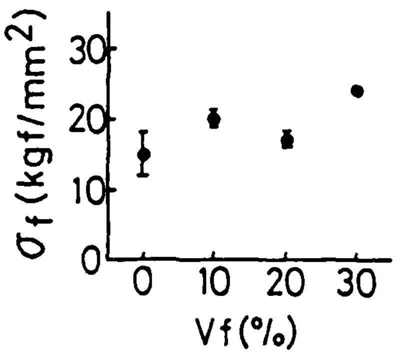


Figure 35. Flexural strength versus volume fraction, V_f, of SiC_w (from Ref 53).

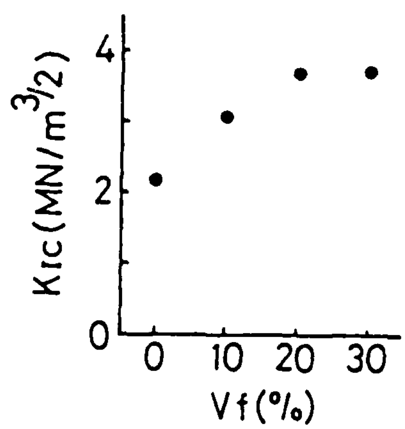


Figure 36. Fracture toughness versus V_f of SiC_w (from Ref 53).

Table 3. Chemical Component and Density of Sintered Material

Chemical Component (wt. %)				Density (g/cm^3)
AlN	SiC_w	Y_2O_3	SiO_2	
100				3.25
80	20			3.18
70	30			3.05
50	50			2.55
70	20	5	5	3.40
50	40	5	5	3.39

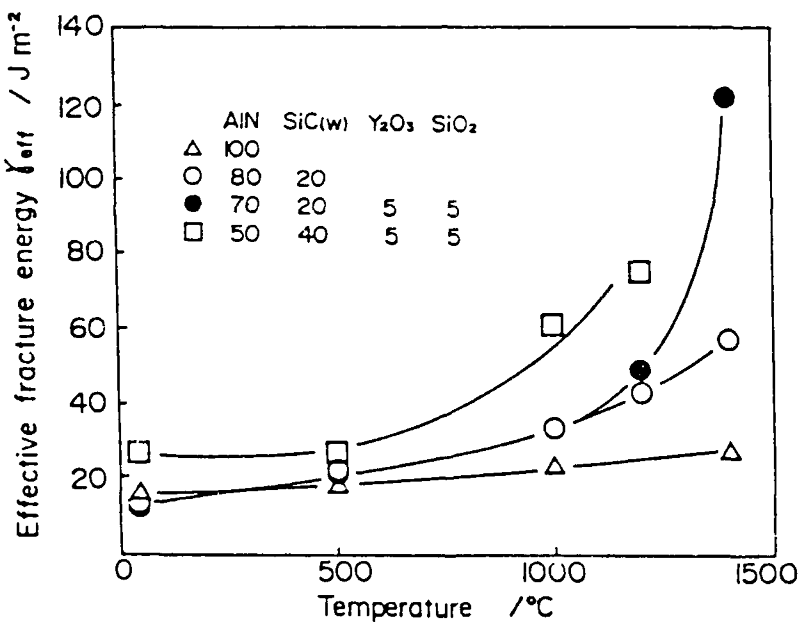


Figure 37. Change in effective fracture energy of SiC_W/AlN as a function of temperature (from Ref 57).

ACKNOWLEDGMENT

The author acknowledges AFOSR/FE for providing the opportunity to write this article and Dr. S. Fujishiro for his continuing interest and encouragement during this project.

REFERENCES

1. J.J. Krochmal, Fiber reinforced ceramics: A review and assessment of their potential, Technical Report AFML-TR-67-207 (Air Force Materials Laboratory, Wright-Patterson AFB, Ohio, October 1967).

2. N. Tamari et al., *Fabrication of SiC Whisker-Si_3N_4 Composite Materials and Their Physical Properties*, Government Industrial Research Institute, Quarterly Report **33** (Osaka, 1982), p. 129.

3. K. Ueno and Y. Toibana, "Mechanical properties of silicon nitride ceramic composite reinforced with silicon carbide whisker," J. Ceram. Soc. Japan **91**, 491 (1983).

4. A. Watts, *Commercial Opportunities for Advanced Composites*, American Society for Testing and Materials, STP No. **704** (Philadelphia, Pa., 1980).

5. O. Sakamoto and S. Ito, "The strength and toughness of SiC-whisker-reinforced glass-ceramics," in *Proc. 24th Basic Discussion Meeting on Ceramics* (Ceramic Society of Japan, Tokyo, 1986), p. 131.

6. J. Oka et al., "Synthesis of SiC whiskers in-situ in SiO_2 powder," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 779.

7. S. Yamada, Opening No. of Japan Patent, Showa-61-219,724, "Manufacturing procedure of modified silica glass" (1986).

8. Y. Kagawa et al., "Physical properties of glass, reinforced with Si_3N_4 and SiC-whiskers prepared from colloidal silica," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 73.

9. Y. Kagawa et al., "Observation of microcrack toughening of glass-matrix composites by AE," Iron and Steel 73 (5), 280 (1987).

10. *Characteristics of the Ceramic Materials*, Catalog (Ceramiques Techniques Desmarquest, Affiliate of Pechney Corp., May 1985).

11. L.M. Sheppard, "Reliable ceramics for heat engines," Advanced Materials and Processes incorporating Metal Progress, 54 (October 1986).

12. K.P. Gadkaree and K. Chyung, "Silicon carbide whisker reinforced glass and glass-ceramic composites," Am. Ceram. Soc. Bull. **65**, 370 (1986).

13. G.K. Layden and K.M. Prewo, Study of SiC whisker reinforced glass and glass-ceramic matrix composites, Final Rept. R85-916943-1 to Office of Naval Research (United Technology Research Center, June 1985) (ONR Contract no. N00014-84-C-0386).

14. S. Kimura et al., "Sintering of SiC-whiskers/oxides ceramics composites," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1986), p. 85.

15. E. Yasuda et al., "Mechanical properties of carbon-coated SiC-whiskers/Al_2O_3 composites," in *Proc. 25th Basic Discussion Meeting on Ceramics* (Ceramic Society of Japan, Toyko, 1987), p. 41.

16. S. Inoue et al., "Preparation and mechanical properties of Al_2O_3/ZrO_2/SiC whisker composites," in *Proc. 24th Basic Discussion Meeting on Ceramics* (Ceramic Society of Japan, Tokyo, 1986), p. 79.

17. S. Inoue and A. Nonaka, "The difference of toughening mechanism between $Al_2O_3/SiC_w/ZrO_2$ (tetragonal) and $Al_2O_3/SiC_w/ZrO_2$ (monoclinic) system," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 265.

18. K. Nakano et al., "Mechanical properties of SiC–whisker reinforced spinel and alumina ceramics," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1986), p. 83.

19. M. Matsubara et al., "Mechanical properties of Al_2O_3–SiC whiskers composites," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 59.

20. N. Iwamoto et al., "Characterization of the sputtered film of whiskers added alumina," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1986), p. 77.

21. P.F. Becher and G.C. Wei, "Toughening behavior in SiC–whisker–reinforced alumina," J. Am. Ceram. Soc. **67**, C–267 (1984).

22. G.C. Wei and P.F. Becher, "Development of SiC–whisker–reinforced ceramics," Am. Ceram. Soc. Bull. **64**, 298 (1985).

23. T.N. Tiegs and P.F. Becher, "Sintered Al_2O_3–SiC–whisker composites," Am. Ceram. Soc. Bull. **66**, 339 (1987).

24. J. Homeny et al., "Processing and mechanical properties of SiC–whisker–Al_2O_3–matrix composites," Am. Ceram. Soc. Bull. **66**, 333 (1987).

25. J.R. Porter et al., "Processing and creep performance of SiC–whisker–reinforced Al_2O_3," Am. Ceram. Soc. Bull. **66**, 343 (1987).

26. A.H. Chokshi and J.R. Porter, "Creep deformation of an alumina matrix composite reinforced with silicon carbide whiskers," J. Am. Ceram. Soc. **68**, C–144 (1985).

27. E. Yasuda et al., "Mechanical properties of SiC whisker reinforced PSZ," in *Proc. 3rd International Conference on the Science and Technology of Zirconia* (Ceramic Society of Japan, Tokyo, 1986), p. 358.

28. I. Kondo and N. Tamari, "Sintering and mechanical properties of SiC whisker–reinforced zirconia," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1986), p. 81.

29. Y. Akimune et al., "Microstructure and mechanical properties of SiC whisker/Y–TZP composite," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 269.

30. T. Miyagawa et al., "Mechanical properties of zircon–silicon carbide whisker composites," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 63.

31. N. Claussen et al., "Tetragonal zirconia polycrystals reinforced with SiC whiskers," J. Am. Ceram. Soc. **69**, 288 (1986).

32. H. Ishigaki et al., "Properties on friction and wear of Si_3N_4-SiC whisker composite ceramics," in *Proc. 30th Spring Meeting, Japan Soc. Lubrication Engineers* (Lubrication Society of Japan, Tokyo, 1986), p. 317.

33. N. Tamari et al., "Electrical discharge machining of Si_3N_4-SiC whisker composite ceramics," J. Ceram. Soc. Japan **94**, 1231 (1986).

34. N. Tamari et al., "Sintering of Si_3N_4/SiC-whiskers composites," in *Proc. 23rd Basic Discussion Meeting on Ceramics* (Ceramic Society of Japan, Tokyo, 1985), p. 84.

35. N. Tamari et al., "Sintering of Si_3N_4-SiC whisker composite," J. Ceram. Soc. Japan **94**, 1177 (1986).

36. I. Kondo et al., "Thermal properties of Si_3N_4-SiC whiskers composite," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1985), p. 693.

37. I. Kondo et al., "Thermal properties of Si_3N_4-SiC whisker composite," J. Ceram. Soc. Japan **94**, 1180 (1986).

38. K. Ueno et al., "Fracture toughness of SiC whisker reinforced Si_3N_4 ceramics," J. Ceram. Soc. Japan **94**, 981 (1986).

39. T. Kandori et al., "Sintered Si_3N_4, reinforced with SiC-whiskers," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1986), p. 133.

40. T. Yonezawa et al., "Properties of Si_3N_4 composites," in *Proc. 25th Basic Discussion Meeting on Ceramics* (Ceramic Society of Japan, Tokyo, 1987), p. 35.

41. T. Yonezawa et al., "Mechanical properties of Si_3N_4-SiC whisker composite," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 69.

42. H. Takemura et al., "Si_3N_4-SiC whisker composites without additives fabricated by HIPing," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 247.

43. S. Yamada et al., "In-situ preparation of SiC whiskers in Si_3N_4 fine powder - A chemical mixing," in *Proc. 6th Basic Discussion Meeting on High Temperature Materials* (Ceramic Society of Japan, Tokyo, 1986), p. 68.

44. S. Yamada et al., "A discussion of the chemical mixing process for in-situ preparation of silicon carbide whiskers in silicon nitride powder," submitted for publication to J. Mat. Research (in press).

45. P.D. Shalek et al., "Hot-pressed SiC whisker/Si_3N_4 matrix composites," Am. Ceram. Soc. Bull. **65**, 351 (1986).

46. R. Lundberg et al., "SiC-whisker-reinforced Si_3N_4 composites," Am. Ceram. Soc. Bull. **66**, 330 (1987).

47. S.T. Buljan et al., "Si_3N_4-SiC composites," Am. Ceram. Soc. Bull. **66**, 347 (1987).

48. S. Sodeoka et al., "Properties of SiC-whisker-reinforced SiC," in *Proc. 23rd Basic Discussion Meeting on Ceramics* (Ceramic Society of Japan, Tokyo, 1985), p. 83.

49. S. Sodeoka, "Mechanical property of SiC whisker-SiC composites," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1986), p. 79.

50. S. Kimura et al., "Mechanical properties of SiC/mullite composites," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1985), p. 637.

51. S. Kanzaki et al., "Mechanical properties of SiC-whisker-reinforced mullite," in *Proc. 24th Basic Discussion Meeting on Ceramics* (Ceramic Society of Japan, Tokyo, 1986), p. 65.

52. H. Kamiaka et al., "Pressureless sintering of mullite SiC whisker composite," in *Proc. Ann. Meeting, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1987), p. 61.

53. K. Nakano et al., "Preparation of sintering material of spinel-SiC whisker composite," in *Proc. Meeting of Tokai Branch, Ceram. Soc. Japan* (Ceramic Society of Japan, Tokyo, 1985), p. 35.

54. S. Inoue et al., "Toughening of ceramic materials by whiskers," Bull. Ceram. Soc. Japan **21**, 621 (1986).

55. N. Claussen and G. Petzow, "Processing and microstructure of SiC whisker reinforced ZrO_2-toughened ceramics (ZTC), in *Extended Abstracts of Tailoring Multiphase and Composite Ceramics* (Pennsylvania State University, University Park, Pa., 1985).

56. T. Nishida et al., "Fracture energy of sintered AlN composite, reinforced by SiC whiskers," in *Proc. 25th Basic Discussion Meeting on Ceramics* (Ceramic Society of Japan, Tokyo, 1987), p. 40.

57. T. Nishida et al., on contribution to J. Soc. Mat. Sci., Japan (in press).

58. F.D. Gac and J.J. Petrovic, "Feasibility of a composite of SiC whiskers in a $MoSi_2$ matrix," J. Am. Ceram. Soc. **68**, C-200 (1985).

59. T. Ishii, *New Century of Japan, Reading a Stream of Technological Civilization* (Toyo Keizai Shimpo, Tokyo, 1982).

Shigehiko Yamada graduated from the Department of Applied Chemistry, Faculty of Engineering, University of Tokyo, in 1950 and obtained a Doctor of Engineering degree from the same university in 1961. Dr. Yamada worked for Tokai Carbon Company, Ltd. (formerly Tokai Electrode Manufacturing Company, Ltd.), in various positions from 1950 until 1984. In 1984 he joined the Industrial Research Institute. Dr. Yamada holds over 50 registered patents. He is a staff member of the Ceramic Society of Japan and a member of the Carbon Society of Japan. Dr. Yamada's areas of interest include carbon and graphite and silicon carbide whiskers.

THE TECHNOLOGICAL UNIVERSITY OF NAGAOKA

Alan L. Dragoo

The Technological University of Nagaoka (TUN) was established in the early 1970s to strengthen creativity in science and technology. In addition to the academic programs, several centers conduct research and support the interdisciplinary program at TUN. This article describes some of the research being conducted at these centers.

INTRODUCTION

During a visit to Japan in March 1987, it was my pleasure to visit the Technological University of Nagaoka (TUN) for a day as the guest of Dr. Kozo Ishizaki. I visited several laboratories during the course of an afternoon and talked with researchers there. Due to the brief time spent at TUN, the following account can only present a superficial and incomplete description of the areas of research that I had the privilege to view.

TUN was established in October 1976 as a government university under the Ministry of Education to strengthen creativity in science and technology. Shinroku Saito, who is president emeritus of the Tokyo Institute of Technology, is president of TUN.

The establishment of the university was brought about in the early 1970s by the Research Committee Concerning Graduate Schools of Technology, the Preparatory Office for the Graduate School of Technology at the Tokyo Institute of Technology, and revision of the National School Education Law. Many of the original faculty as well as research equipment came from the Tokyo Institute of Technology.

Today the TUN campus consists of a network of modern buildings that are interconnected by covered walkways. The faculty has grown with the addition of younger members from a variety of universities and backgrounds. Many of the laboratories contain instruments of recent manufacture.

The curriculum at TUN is designed to attain the goal of training engineers and scientists who are innovative and creative but who are also trained to transform new ideas into practical applications. To accomplish this goal, the curriculum is interdisciplinary and includes required "on-the-job" experience in industry. The student body is small, about 1,300 students, and of high intellectual caliber. There are about 180 faculty members.

Most students enter TUN as third-year undergraduate students upon completion of 5-year technical college programs. These entering students are roughly equivalent to students who have completed 2 years of undergraduate engineering study in the U.S. A small number of students are admitted from 3-year technical high schools as first-year undergraduates. The enrollment system is intended to provide a student body heavily weighted to upper level undergraduate and graduate level students so that high academic and research ability is present in the university's technical program.

Areas of study include mechanical systems engineering, planning and production engineering, electrical and electronic systems engineering, electronic (materials) engineering, material

science and technology, and civil engineering. In addition to the academic programs, several centers, such as the Analysis Center described below, conduct research and support the interdisciplinary program at TUN.

As a new technological university, the laboratories at TUN are very well equipped. Brief descriptions of some of the laboratories are presented here.

LABORATORY VISITS

Material Science

Research is being carried out on powder synthesis and preparation, hot-pressing and hot-isostatic pressing (HIP), microstructural development, and physical and chemical characterization of surfaces.

Electron diffraction and lattice imaging studies on Sr-Ba ferrite intergrowth, the electronic structure of vanadium oxides, and ceramic metal interfaces were described by Dr. Yoshihiko Hirotsu. Dr. Hirotsu's research interests include the solid state chemistry of electronic and structural ceramics. A JEOL JAMP-13 Auger spectrometer recently was acquired for this work.

Other instruments for materials characterization include a laser flash apparatus for measurement of heat capacity and thermal conductivity. This instrument is being used to study sintering effects on alpha/beta silicon nitride composition.

An ESM-3200 Elionix scanning electron microscope (SEM), which is equipped with two detectors, provides a capability for depth profile analysis with a resolution of 2 nm.

Dr. Ishizaki is constructing a HIP map (temperature-pressure-time) for the sintering of silicon nitride and silicon carbide. The HIP apparatus used is a NKK-ASEA instrument, with operating capabilities of 2,000 °C and 200 MPa (2,000 atm), and with chamber dimensions of 152 mm diameter by 305 mm high. A Fujidempage-10 hot-press provides a means for sintering materials with sustained temperatures of 2,200 °C and loads of 10 metric tons. The hot-press uses inductively heated graphite molds with either 25- or 50-mm internal diameters.

Starting powders for these studies are produced at TUN or are obtained from commercial sources. TUN synthesis methods include an arc plasma unit that has been used to generate SiC, Fe, Si_3N_4, SiO_2, and Si powders. An Ar/H_2 plasma with an effective temperature in excess of 10^4 °C impinges on a suitable substrate, and powder is obtained as a condensate from the evaporated or sublimed material.

Ion Beam Physics

A description of the ion beam apparatus, ETIGO-II, was provided by Dr. Yatsui. This ion beam unit is rated at 3 MeV and is the largest in Japan. Studies of ion pulses are in progress. A projected fusion device, ETIGO-IV, will incorporate 36 of the ETIGO-II type ion beam units.

Analysis Center

Research in the Analysis Center includes catalytic materials and metal organic complexes. Several projects on the surface science of materials were described by Dr. Inoue. Investigations of the effects of electric fields and of illumination on surface states of semiconducting oxides are being carried out. Gas adsorption is studied by temperature programmed desorption (TPD) in which a gas is adsorbed on a cooled sample, the sample is heated at a programmed linear rate, the current proportional to the rate of desorption is measured, and the heat of desorption is obtained. A SIMS unit, in which a beam

of heavy ions impinges obliquely on the surface of a material, is used to examine the effect of adsorbed gases on the composition of molecular fragments sputtered from the surface of the substrate. Sputtering units are available for the production of thin oxide films.

A Rigaku x-ray generator is equipped with both a small-angle x-ray scattering unit and a goniometer for x-ray diffraction. A JEOL nmr spectrometer, using H, C, or ^{19}F resonances, is used for identification of structures in organic compounds and organometallic complexes. This fully automated instrument enables data to be rapidly collected and displayed. Elemental analysis is provided with a JEOL Superprobe 733 equipped with two wavelength dispersive x-ray spectrometers and an energy dispersive spectrometer. A Shimadzu Auto GCMS-6020s, which is presently only equipped with a port for liquid injection, is scheduled to be directly coupled to a gas train. A Hitachi IMA-S ion microanalyzer equipped with a 10-keV ion source and dual tandem mass analyzers is available for depth profiling of compositions. The tandem mass analyzer enables the resolution of different isotopic masses to be achieved.

CONCLUSION

TUN is dedicated to the education of creative scientists and engineers. To do this, it has a highly focused program and an academically advanced student body. The small size of the university and its interdisciplinary program foster a sense of awareness and collaboration between departments. The research laboratories I visited appeared to be well-equipped with near state-of-the-art equipment. From the standpoints of its high caliber student body and faculty and its research facilities, TUN appears well-positioned to achieve its goal of training innovative, practically oriented engineers and scientists.

ACKNOWLEDGMENT

I wish to thank Prof. Ishizaki for the opportunity to visit the Technological University of Nagaoka and for providing corrections to this report.

Alan Dragoo has a background in both chemistry and physics, having earned B.S. (1961) and M.S. (1963) degrees in chemistry from the University of Michigan and a Ph.D. in physics from the University of Maryland (1975). He has 24 years of research experience at the National Bureau of Standards, both before and after receiving the Ph.D. His work has included experimental and theoretical studies of mass transport in ionic crystals, theoretical work on the Marangoni effect (convective flow in liquids which is driven thermally or chemically through surface tension gradients), measurements of elastic constants, theoretical modeling of chemical bonds in ionic compounds, preparation and characterization of highly dense and pure ceramic research materials, and experimental x-ray diffraction studies of phases formed on silicon carbide ceramics by corrosive reactions. He has been the author or coauthor of 22 papers in his field. Dr. Dragoo is currently Group Leader of the Ceramic Powder Characterization Group.

FIRST INTERNATIONAL WORKSHOP ON MULLITE: NEW DEVELOPMENTS FOR AN OLD MATERIAL

Edward S. Chen

The First International Workshop on Mullite focused on four major topics: phase equilibria, crystal structure, processing and properties, and composites. This article summarizes some of the more interesting developments, problems, and opportunities presented at the workshop.

INTRODUCTION

The First International Workshop on Mullite was held on 9–10 November 1987 in Tokyo, Japan. The workshop agenda included 24 oral presentations and 40 poster sessions focusing on four major topics: phase equilibria, crystal structure, processing and properties, and composites. Considering the potential of mullite for structural applications, the current workshop devoted a major portion of the program to recent advancements in the processing and characterization of the physical and mechanical properties of mullite. The following summary reflects some of the more interesting developments, problems, and opportunities.

PHASE EQUILIBRIA

Mullite belongs to the Al_2O_3–SiO_2 system for which a simple, albeit controversial, phase relationship is known. It forms in the solid solution range between 71.8 and 74.3 wt. % Al_2O_3 approximating the 3:2 ($3Al_2O_3$–$2SiO_2$) and the 2:1 ($2Al_2O_3$–SiO_2) alloys. However, leading researchers disagree on the melting point of mullite, the reported values of which vary from 1,825 to 1,890 °C. Dr. Pask, University of California at Berkeley, suggested in concert with others in his field that one should consider the experimental data to be correct but that such data should be interpreted from both a metastable and a thermodynamically stable system viewpoint. Dr. Pask also emphasized the need to look beyond the 3:2 mullite alloy to examine the influence of precipitated αAl_2O_3 and glassy SiO_2 in the two phase regions at higher and lower Al_2O_3 concentrations.

PROCESSING

As with all ceramics, mullite can be produced optimally when proper procedures are applied to each of the processing categories of powder synthesis, consolidation, drying, and sintering. In powder synthesis, it is necessary to produce high purity fine powders and this can be done through sol-gel, hydrothermal, chemical vapor deposition (CVD), and pyrolytic techniques. A fine powder is desirable because it increases the surface energy of the particulate system and thus the driving force for sintering. Under these conditions, sintering occurs at a lower temperature, reaction kinetics are accelerated, and a finer grained ceramic is produced. As powder size decreases, however, powder agglomeration increases. When this occurs, one finds that the packing density of the green compacts cannot be optimized and an intolerable number of pores persist in the sintered product.

Recent studies have illustrated the potential of reducing particle agglomerization using colloidal consolidation methods. One such development was reported by Kureha Chemical Industry Company. Kureha succeeded in producing uniform colloidal dispersions by stabilizing the powder particles with a polymeric coating. Using this procedure, Kureha

produced green mullite compacts by filtration where the sintered product reached 99.8 percent of theoretical density.

An important consideration in the preparation of mullite is to reduce manufacturing costs in order that mullite may compete successfully with other ceramics. One approach is to use reaction sintering whereby MgO, TiO_2, and ZrO_2 are added to produce consolidation through a liquid phase. Two benefits come to mind. First, reaction sintering enables one to use conventional pressureless sintering techniques and at reduced temperatures. Second, it is a particularly effective method of incorporating ZrO_2 into the mullite matrix to provide inproved mechanical properties. Several papers reported on such improvements. The astonishing development is that the improved properties did not come about through the anticipated (t–ZrO_2) transformation toughening. Instead, homogeneous monoclinic ZrO_2 dispersions inter-twined with a crosslinked arrangement of mullite grains were found. Within this arrangement, crack propagation must follow a tortuous path and crack detection and bridging mechanisms contribute to the enhancement of strength.

STRENGTHENING

Mullite is a ceramic that is often overlooked for high temperature applications in spite of its impressive properties such as refractoriness, chemical inertness, thermal stability, and creep resistance. In actuality, it only needs to have improved fracture toughness and strength to have an impact in this application. In the current workshop, conclusions drawn from studies on mullite strengthening using ZrO_2 alloying, SiC whisker reinforcement, and diphasic mullite with amorphous SiO_2 tend to support this view. In general, all three procedures produced favorable room temperature property improvements. Typically, bending strengths were increased from 200 to over 500 MPa and fracture toughness values, K_{IC}, were improved from 2 to 7 MPa$\sqrt{m}$.

While the strengthening procedures produced comparable room temperature property data, this was not the case at high temperatures. In reaction sintered alloys, the tendency to form an intergranular amorphous phase in MgO-ZrO_2-mullite and the recrystallization of aluminum titanate in TiO_2-ZrO_2-mullite alloys are detrimental to strength at temperatures above 800 °C. A possible solution is to use higher purity powders to minimize interactions between impurities and the amorphous phases. SiC whisker reinforcement showed a small negative coefficient of strength up to 1,000 °C, at which temperature the bending strength was still 450 MPa. However, SiC whisker reinforcement is lacking in two respects. One is an unexplained tenfold decrease in creep resistance. The other is the decomposition of SiC in mullite at temperatures above 1,400 °C. The obvious solution here is to switch to an oxide whisker for reinforcement. Perhaps the most dramatic development is that reported by the Government Industrial Research Institute of Nagoya and the Technical Research Laboratory of Mino Yogyo Company on the characterization of mullite in the two-phase region (68 wt. % Al_2O_3), where one component is a glassy SiO_2 phase. The bending strength of this alloy peaks at 1,300 °C at about 475 MPa. The high temperature strength of this alloy compares favorably with gas pressure sintered Si_3N_4 currently used in turbine rotors.

Figure 1 compares the flexural strengths of gas pressure sintered Si_3N_4 prepared by NGK and Mitsubishi with mullite produced by the sintering of spray-dried powder containing 68 wt. % Al_2O_3. The NGK data were obtained at

0.5 mm/min using a three-point bend test. The test conditions for the remaining two curves were not specified. One should not look at this figure and make an arbitrary judgment on which material is better since such judgments depend on application requirements. Nevertheless, when one considers that the inlet temperature of the Garret turbine engine peaks at 1,370 °C, the current developments in mullite assume greater importance.

Edward S. Chen, Associate Director of the Office of Naval Research, Air Force Office of Scientific Research, and Army Research Office (ARO), Far East Liaison Office in Tokyo since December 1986, has been a program manager in the Materials Science Division at ARO in North Carolina since April 1986. He attended Rensselaer Polytechnic Institute where he received a B.S. degree in chemical engineering in 1959 and a Ph.D. degree in physical chemistry in 1964. From 1964 to 1986 Dr. Chen worked at Benet Weapons Laboratory in New York, initially as a group leader studying dispersion-strengthened materials, as Chief of Electrochemical Processing in 1973, and as Chief of the Physical Sciences Section in 1983. Dr. Chen is a member of the Electrochemical Society and ASM. His research interests currently include the relationship between processing parameters and mechanical properties of ceramic and composite materials and electrochemical processing in the electronics industry.

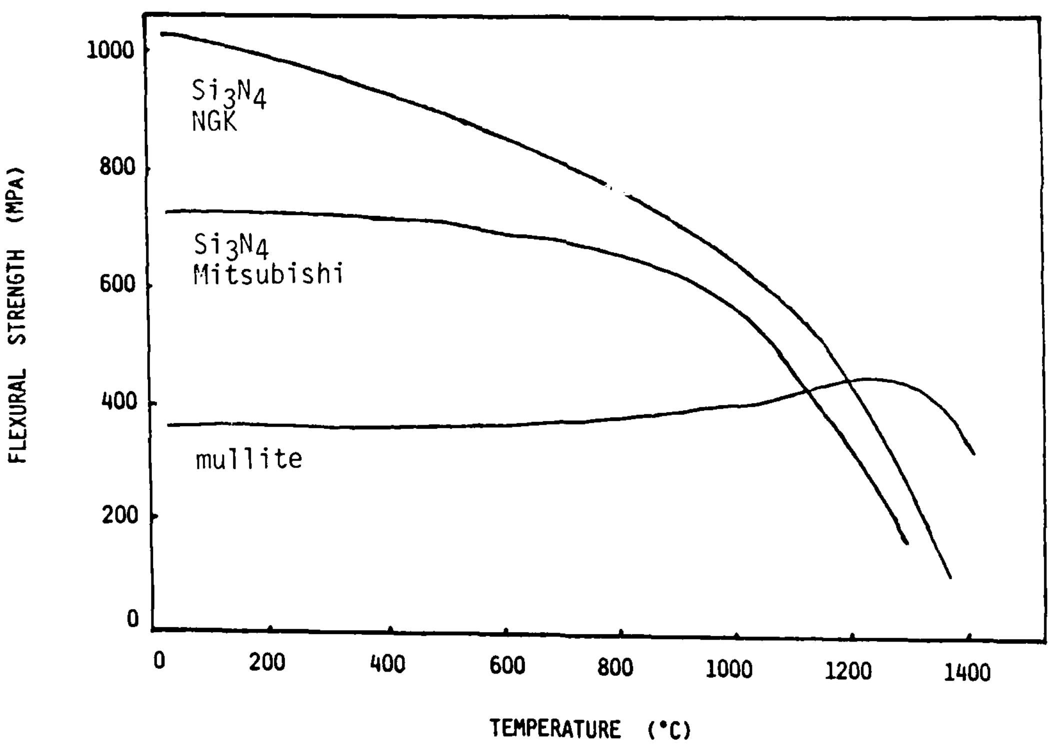


Figure 1. Comparisons of flexural strengths of gas pressure sintered Si_3N_4 prepared by NGK and Mitsubishi with mullite produced by sintering of spray-dried powder containing 68 wt. % Al_2O_3.

SOLAR PHYSICS ACTIVITIES IN JAPAN

Tokio Tsubaki

This article describes the major solar observatories in Japan and surveys the research activities in solar physics during the past 5 years.

INTRODUCTION

The Astronomical Society of Japan is composed of three types of memberships, special, ordinary, and corporate, consisting, respectively, of 660, 1,588, and 50 members as of 30 June 1987. The special membership corresponds to the mixture of junior, associate, full, and emeritus memberships as in the American Astronomical Society, and the ordinary membership is mostly for amateur astronomers. Most of the research has been conducted by the special members, although amateur astronomers have been making a great contribution to some fields, such as in discovering a new comet or a nova event. The society makes it a rule to hold a general meeting twice a year, in the spring and fall, during which the overall aspects of research activities progressing in Japan are discussed.

In this article, the major observatories are described and the current activities in solar physics that were discussed in papers given at the general meetings of the Astronomical Society of Japan are surveyed.

SOLAR OBSERVATORIES

Several important solar observatories are now in active service both for optical and radio observations.

Norikura Solar Observatory

Located on top of Norikura Mountains (137°33.3' E., 36°6.8' N.) at an altitude of 2,876 meters, this observatory belongs to Tokyo Astronomical Observatory, University of Tokyo. This facility has a 25-cm Coudé type coronagraph and attached spectrograph, which are used for observing not only the corona but various phenomena appearing at the chromospheric and photospheric levels, such as prominences, spicules, faculae, sunspots, and flares. Another 10-cm coronagraph is mainly used for obtaining monochromatic images of the corona in Fe XIV 5303 coronal emission.

Hida Observatory

This observatory, which is part of the Faculty of Science, University of Kyoto, is located at 137°18' E., 36°5' N. and 1,276 meters above sea level in the mountainous area of Hida, about 20 km west of the Norikura Solar Observatory. The principal instrument is the 60-cm domeless solar telescope, which is equipped with two spectrographs, a vertical and horizontal. The domeless structure, cooled tower surface, and evacuated optical channel suppress air turbulence around and inside the telescope, resulting in high resolution. Because of the high resolution, this telescope is being used by many researchers from various institutes in Japan.

Okayama Astrophysical Observatory

The Okayama Astrophysical Observatory, a station of the Tokyo Astronomical Observatory, University of Tokyo, is located on Mt. Chikurinji at 133°35.8' E., 34°34.4' N. and 360 meters above sea level. The

principal instruments are a 60-cm Coudé telescope and a 10-meter horizontal Littrow spectrograph to which a vector magnetograph has been recently installed. The magnetograph, which is a unique instrument in this country, supplies daily magnetic data on the sun.

Kwasan Observatory

A sister observatory of Hida Observatory, also belonging to the Faculty of Science, University of Kyoto, this facility is located on a small hill in the city of Kyoto, about 200 meters above sea level. A 50-cm horizontal telescope with a 70-cm coelostat and a 15-meter spectrograph are the main instruments. This system is now used not only for solar research but for educational purposes for the students at Kyoto University.

Nobeyama Solar Radio Observatory

This observatory, a station of Tokyo Astronomical Observatory, is located on Nobeyama Heights at an altitude of 1,350 meters. Two sets of radio telescopes are the principal instruments: one is a 160-MHz interferometer consisting of 17 parabolic antennas of 6- to 8-meter apertures, and the other is a 17-GHz interferometer with 17 sets of 1.2-meter antennas. These instruments are used not only for obtaining a high resolution image but also for observing radio emissions over a wide wavelength range.

Toyokawa Observatory, the Research Institute of Atmospherics

The Toyokawa Observatory, located in the city of Toyokawa, belongs to Nagoya University. The observatory contains two sets of radio heliographs with fine resolution. The 3.75-GHz heliograph, with a spatial resolution of 1 arc minute, consists of 52 sets of 3-meter-aperture parabolic antennas; the 9.4-GHz heliograph consist of 50 sets of 1.2-meter-aperture antennas. Besides these, there is another telescope for observing radio flux simultaneously at the following four wavelength ranges: 1,000, 2,000, 3,750, and 9,400 MHz.

Others

There are some other observation facilities that are smaller but more convenient for daily observations because they are installed at each institute. For example, a radio telescope (interferometer) is installed on the campus of Nagoya University for making observations at millimeter wavelength range. At Shiga University, a 30-cm-aperture vertical telescope with 50-cm cidelostat and 7-meter horizontal spectrograph was installed recently. At other institutes, 10- to 20-cm solar telescopes are being used not only for research but for educational purposes.

RESEARCH ACTIVITIES

Table 1 summarizes the number of papers on solar physics and the total number of papers, both presented at the general meetings held during the past 5 years and during the same period 20 years ago, along with the corresponding number of special members.

As seen in this table, the percentage of solar physics papers compared to those in all fields has decreased from about 20 to 12 percent during the past 20 years, thereby suggesting that solar physics activities have considerably diminished at least in the sense of relative numbers. Note, however, that the actual numbers have increased from about 30 to 52 papers a

year, that is, by a factor of 1.75. The total number of papers and the membership have increased during this period by factors of 2.81 and 2.17, respectively. It is clear from these results that research activities in other fields, such as galaxy, high energy astrophysics, cosmology, and observation or data-reduction facilities, have increased at a much higher rate.

For surveying research activities on solar physics, a statistical analysis has been made of the papers presented during the past 5 years at the general meetings of the Astronomical Society of Japan. The results are summarized in Table 2.

As clearly shown in this table, the outstanding research field during the past 5 years has been the investigation of flares, a dynamic, explosive phenomenon of the active chromosphere. The reason for such a flurry of activity in this field is the flare observation satellite, HINOTORI, meaning firebird, sunbird, or phoenix. HINOTORI was successfully launched in early 1981 when the sun's activity was at its maximum phase and provided an enormous number of flare observations in the wavelength ranges from hard to soft x-ray. Using these data, a lot of flare research was carried out by the extended collaboration of many people from many institutes.

Table 1. Number of Papers Presented at the General Meetings and the Number of Special Members of the Astronomical Society of Japan

Year	Solar Physics	All Fields	No. of Members	Year	Solar Physics	All Fields	No. of Members
1962	41	141	252	1982	54	386	521
63	26	163	257	83	52	419	538
64	27	149	250	84	53	420	549
65	21	129	260	85	50	445	569
66	34	169	265	86	51	443	604
Total	149	751	--	Total	260	2113	--
Mean	29.8	150.2	256.8	Mean	52.0	422.6	556.2
% of Total	19.8			% of Total	12.3		

Table 2. Number of Papers in Nine Prominent Research Fields or Topics of Solar Physics Presented During the Past 5 Years at the General Meetings of the Astronomical Society of Japan

Research Field	1982	1983	1984	1985	1986	Total	Percentage of Total
Theoretical studies	6	3	3	5	3	20	7.7
Sunspot & magnetic field	3	4	3	5	6	21	8.1
Spicule & surge	1	3	1	2	6	13	5.0
Prominence	4	3	6	3	8	24	9.2
Corona	3	4	2	9	6	24	9.2
Solar wind & IPS[a]	3	2	0	3	3	11	4.2
Flare	20	19	23	16	8	86	33.1
Radio & x-ray burst	8	7	6	2	3	26	10.0
Other fields	6	7	9	5	8	35	13.5
Total	54	52	53	50	51	260	100

[a]IPS = Interplanetary space.

The second prominent topic, radio and x-ray burst, also has an important relationship, more or less, with the results from HINOTORI. Since it is well known that the time profile of the radio burst coincides well with that of the x-ray burst, cooperative work with a ground-based radio telescope was extensively carried out. These observations, together with the results of the Solar Maximum Mission (SMM) satellite, have brought a number of new findings to the investigations of flare and burst.

Research for clarifying the physical structures of the corona, prominences, spicules, and surges has continued, mainly by using optical telescopes such as the domeless solar telescope at the Hida Observatory and the coronagraph at the Norikura Solar Observatory. The research topics include periodic oscillations, energy releases, internal motions, evolutions, temperatures, and so on. Using the vector magnetograph, which was recently attached to the Coudé telescope at the Okayama Astrophysical Observatory, magnetic structures inside and around sunspots have been studied energetically. It should be noted here that a lot of effort had been made to develop, construct, and adjust the instrument before public use.

Theoretical studies have also continued to elucidate the physical process changing slowly in the convection zone, which is the origin of the solar cycle, one of the biggest problems still unknown. Global oscillations and helio seismology are the newest tools for studying the sun's deep interior. Combinations of theories and observations are being applied to the research on solar wind and interplanetary space. In this case, most observations have been made at the Toyokawa Observatory.

INSTITUTE ACTIVITIES

Statistical analyses have been made to see how many papers have been presented by each institute at the general meetings during the past 5 years. For a paper written by two or more authors belonging to different institutes, fractional numbers (=1/numbers of coauthors) were equally given to each institute; that is, no special weight was given even to the first author. The results are summarized in Table 3.

As seen in Table 3, there are three big groups showing prominent activities in the field of solar physics: Tokyo University, Nagoya University, and Kyoto University, each having a productive share of 36.5, 11.7, and 25.8 percent, respectively. Note, however, that since these groups are composed, respectively, of the observatory and the department, contributions both by the graduate students and by the peripheral researchers graduated from the corresponding department are considerable.

The Institute of Space and Astronautical Sciences contributed greatly to constructing, launching, and operating the satellite HINOTORI, but there are very few solar physics majors on the staff. There are many minor institutes with only one or two solar physicists showing relatively good activities, such as the Department of Physics, Rikkyo University, and the Department of Earth Science, Shiga University. It should also be mentioned here that the recent increase of activity by other institutes depends considerably on the fact that studies done by collaborating with foreign researchers have increased greatly.

Tokio Tsubaki, from Tokyo, Japan, graduated from the School of Science, University of Kyoto, in 1959; he continued graduate studies there in astrophysics (emphasizing solar physics) until the end of 1964, when he accepted a position as a lecturer at Ohita University, Faculty of Education. In 1967 he was awarded a Ph.D. degree from the University of Kyoto for his thesis titled "A New Model of the Coronal Condensation." After being promoted to an associate professor, Dr. Tsubaki accepted a position with the Faculty of Education, Shiga University, where he was promoted to a professor in 1976. To further his studies of the solar corona, Dr. Tsubaki joined several Kyoto University expeditions to observe solar eclipses (the South Pacific, 1965; Mexico, 1970; West Africa, 1973). Between 1973 and 1975, he was a postdoctoral research associate of the National Academy of Science/National Research Council of the United States doing coronal research at Sacramento Peak Observatory, Sunspot, New Mexico. Dr. Tsubaki's current research interests include detecting oscillatory phenomena in the solar corona and prominences.

Table 3. Number of Solar Physics Papers per Institute Presented During the Past 5 Years at the General Meetings of the Astronomical Society of Japan

Institute	1982	1983	1984	1985	1986	Total	Percentage of Total
Tokyo Astronomical Observatory, Tokyo University	13.2	12.5	14.9	13.2	12.6	66.4	25.5
Department of Astronomy, Tokyo University	8.9	8.8	4.4	3.6	2.8	28.5	11.0
Institute of Space & Astronautical Science	3.4	0.9	1.2	0.0	0.3	5.8	2.2
Department of Physics, Rikkyo University	1.7	1.8	1.2	1.3	2.2	8.2	3.1
Research Institute of Atmospherics, Nagoya University	4.0	3.8	3.9	3.9	4.6	20.2	7.8
Department of Astrophysics, Nagoya University	2.4	4.8	3.0	0.0	0.0	10.2	3.9
Department of Earth Science, Shiga University	0.5	0.0	1.3	2.7	4.9	9.4	3.6
Kwasan & Hida Observatories, Kyoto University	7.0	8.9	11.3	10.2	8.0	45.4	17.5
Department of Astronomy, Kyoto University	6.0	4.6	3.3	2.1	5.6	21.6	8.3
Other Institutes	6.9	5.8	8.4	13.1	10.0	44.2	17.0
Total	54.0	51.9	52.9	50.1	51.0	259.9	99.9

A REVIEW OF THE STATE–OF–THE–ART IN ROLLING ELEMENT BEARING TECHNOLOGY IN JAPAN

James F. Dill, Robert A. Harmon, and Edward Mark Lenoe

Recently the authors had the opportunity to attend the International Exhibits at the 1987 Nagoya Ceramics Fair and to participate in the International Workshop for Advanced Materials in the same city. In addition, a preliminary survey of rolling element bearing technology in Japan was conducted. For this purpose three principal bearing manufacturers, two ceramic materials suppliers, and one aircraft engine manufacturer were visited. In the aircraft quality bearing area, based on the facilities visited and the ensuing discussions, there is no question that all three companies have the capability to produce bearings of the quality required for the highest performance applications. The depth of understanding and level of sophistication of research into bearing dynamics, fatigue life, failure modes, and advanced materials demonstrated the very solid basis of bearing technology in Japan. Fundamental input and research support from leading universities and research institutes were an integral part of the research and development structure within each organization and its sphere of influence. Regarding ceramics, the capability to produce high–performance, spindle–quality, ceramic bearing components clearly exists in Japan. All of the companies visited are in the process of testing or introducing both hybrid steel/ceramic and full ceramic bearings into appropriate markets. Limited quantities of silicon nitride rolling element bearings have been in production over the last 2 to 4 years. It was evident that bearing suppliers in Japan are strong worldwide corporations intent on successful development of advanced technology.

BACKGROUND

Rolling element bearings, while not typically viewed as high tech products, are a critical component for a wide range of both commercial and military systems. Automobiles, trucks, airplanes, electric motors, ships, machine tools, robots, microchip processing systems, satellites, rockets, the list could go on for pages. Our lives are influenced daily by systems that depend on the availability of highly reliable, low noise, low cost rolling element bearings.

As might be expected, some of the most demanding applications for rolling element bearings are in the aerospace industry and in particular aircraft turbine engines. Both commercial and military aircraft turbine engines require highly reliable rolling element bearings for their performance. Since a bearing failure in an aircraft turbine engine could seriously risk aircraft safety, a zero failure philosophy is followed in designing and manufacturing these bearings. At the same time, these systems require bearings to operate under some of the most demanding conditions of speed, load, and temperature. To meet the demands of aircraft turbine engine manufacturers, bearing companies have been forced to achieve levels of precision found in few other industries and to use materials of the highest quality (essentially inclusion and void free).

Dimensional measurements in the micron range are routine in the rolling element bearing industry and measurements to 0.1 micron or less are relatively common. Surface finishes required are even more precise with levels as low as 0.005 micron being achieved on some components. To insure material quality and cleanliness, the steel is typically either double vacuum melted or electroslag remelted; in addition, it is frequently ultrasonically inspected to insure that the desired quality is achieved.

In addition to these high demands for precision and material quality, each bearing used in the mainshaft section of a turbine engine is a unique, application-specific design. Frequently, many special features, such as special mounting brackets or flanges or at times even portions of the engine structure, are included in the bearing design. This requirement for application-specific designs results in small lot size orders for any given bearing.

This combination of high precision, small lot sizes, and special design features makes the aircraft bearing business very labor and capital intensive. While prices for aircraft quality bearings can be quite high (frequently in the $1,000 to $10,000 range for a single bearing), manufacturing costs are also high at the same time because the bearing industry world-wide is very competitive and profit margins are small. Because of the age of facilities and current economic conditions, coupled with the nature of this business, it has become increasingly difficult for U.S. bearing suppliers to compete with foreign bearing manufacturers. Foreign suppliers have captured much of the higher profit, lower performance bearing business, leaving only the smaller, high-precision business to U.S. suppliers. With their production base reduced, U.S. suppliers have found it harder than ever to invest in modernizing their high-precision bearing plants, resulting in the current situation where there is now concern that this business will also be lost to overseas suppliers.

At the same time, while competition for current bearing production is becoming increasingly difficult for U.S. suppliers, advanced systems are being developed that could significantly change requirements over the next 5 to 10 years. Therefore, any efforts to modernize the U.S. bearing industry must consider not only how to make current products better and at lower cost but also what production capabilities will be required to meet these future requirements.

To assess the capabilities of U.S. bearing suppliers relative to their foreign competition, to determine the status of the bearing industry worldwide, and to assess future directions in bearing technology, we undertook a review of bearing technology in Japan. The results of this review are discussed in this article. Topics covered include: general comments on the Japanese bearing industry; observations on Japanese aircraft quality bearing manufacturing; and observations on ceramic bearing technology, which is an important technology for meeting future systems needs.

SURVEY OF JAPANESE INDUSTRY

To achieve a realistic perspective on the status, trends, and outlook for precision rolling element bearings and the related production facilities in Japan, the principal bearing manufacturers were identified; visits were arranged with:

- Nippon Seiko K.K. (NSK), Research Center and Precision Bearing Production Facility in Fujisawa

- Nippon Seiko K.K. (NSK), Otsu Production Plant near Kyoto
- Koyo Seiko Co., Ltd., Kokubu Plant near Osaka
- NTN-Toyo Bearing Co., Ltd., Kuwana Plant

To add perspective, two materials suppliers and the major Japanese aircraft engine manufacturer were also visited:

- Kyocera Corporation in Kyoto
- Toshiba Corporation, New Materials Department in Yokohama
- Ishikawajima-Harima Heavy Industries (IHI) in Tokyo

Members of our group participating in the visits are included as Appendix A. A list of key personnel contacted at each company is given in Appendix B.

In addition, visits were made to the international exhibits at the Nagoya Ceramic Fair, and Dr. James Dill of Mechanical Technology, Inc. (MTI), presented an invited lecture to the International Workshop for Advanced Materials Technology-Ceramics II: Characterization of Ceramics and Development of International Standards. His topic was "High Temperature Testing in Tribology." This was also held in Nagoya. These activities took place from 9-19 March 1987.

OBSERVATIONS AND RESULTS

The three bearing companies visited comprise the three largest Japanese suppliers. NSK is the largest in Japan and one of the largest bearing companies world-wide. NTN is second in size in Japan, and Koyo is somewhat smaller.

In general, significant research was being conducted at all three companies. The most impressive facilities were found at NSK in Fujisawa. All three companies viewed their business on a world-wide basis and in general had both international production facilities and distribution networks in addition to their Japanese facilities.

In the aircraft quality bearing area, two of the companies had facilities that had been constructed very recently, one having been opened in the last 6 months and the second completed within the last 2 years. These facilities, in general, had primarily new machines; the machines were mainly of Japanese manufacture although some were from U.S. and European suppliers. Based on the facilities visited and the experience discussed, there is no question that all three companies have the capability to produce bearings of the quality required for the highest performance military applications. ***Relative to production for military applications of their products, all of the companies pointed out that the Japanese constitution restricts them for exporting goods for this purpose.*** Because of this restriction, all three companies are emphasizing marketing and production for the commercial aviation market.

The depth of understanding and sophistication of the research into the areas of bearing dynamics, fatigue life, modes of failure, and advanced materials shows that the current high level of bearing technology in Japan is on a broad solid footing. Fundamental input and research support from leading universities and research institutes are an integral part of the research and development structure within each organization and its sphere of influence. Constant attention to high quality and performance permeates all of the organizations visited.

Recent technical publications from some of the companies visited are indicative of the technical depth and detail being focused on rolling element bearings and their related technologies. A list of some recent references provided during visits is included as Appendix C. In general, the focus is on understanding the details of materials properties and characteristics and their influence on the behavior, performance, and life of bearings in the environment of the application. In bridging the gap from properties to application, a number of test rigs and simulators are used to examine the behavior of materials and components under simulated environmental operating conditions. Feedback from failure mode analyses and analytical investigations is used to improve the design and to better predict the life and reliability of their products.

The following is a list of highlights, significant observations, and apparent trends based on the various plant visits.

General Bearing Industry Comments

- The Japanese bearing companies visited were all full-range bearing manufacturers, each producing bearings ranging in quality level from ABEC 1 to ABEC 9. As in the United States, Japanese aircraft bearing production involves small lot sizes of special bearing designs for each application. In the production of such special bearings, there is close cooperation with the customer.

- As in the United States, each bearing manufacturer has a group of trusted subcontractors and suppliers it depends upon. Some subcontracted items include material stock, finished rolling elements, retainers, retainer plating, and race forging.

- The Japanese bearing companies use primarily Japanese steel suppliers, but they will purchase steel from either U.S. or European sources if necessary. U.S. sources mentioned included Latrobe and Carpenter. There are Japanese suppliers of all major bearing materials capable of meeting the tightest aircraft specifications. Two Japanese suppliers cited were Hitachi Metals and Daido Steel.

- Bearing manufacturers produce components from a full range of materials including typical U.S. alloys (52100, M-50, and 440C), European alloys such as 18-4-1, and Japanese alloys such as SUJ2 and SKH4. They are also beginning to work with the new carburizing alloy M-50NiL, developed in the United States specifically for the high shaft speed aircraft bearing application.

- Production facilities for ABEC 1 bearings (for applications like commercial and automotive equipment) are highly automated. Pride was taken in the care with which the process was monitored. In one area, it was pointed out that while there were 21 processes involved in machining a particular part, there were 23 inspection processes to insure that the part was correct.

- In the automated production line, all gauging was in line and primarily between processes. Parts that didn't meet a specified tolerance were automatically rejected. If a machine started producing parts out of tolerance because of misadjustment or tool wear, a warning light would come on to notify a machine operator. Machine operators would monitor the performance of a series of machines on a given production line, performing adjustments as necessary.

- In manufacturing general-purpose bearings, production progress, rates, and outages were monitored and posted in various areas of the plant. These charts showed performance for the given area as well as overall plant performance. The goal of the staff was to produce no rejected parts, which while not achieved was approached very closely.

- As in the United States, ball manufacture is treated as a specialized operation and is usually handled off-site by a specialty plant or separate company. No detailed information was gathered on ball manufacture.

Aircraft Engine Bearings

- Because of the higher precision required and the smaller lot sizes, high-performance bearings for aircraft engines, other aerospace applications, and precision spindles were generally manufactured in separate facilities.

- At present, U.S. operations for the companies visited are directed toward manufacture of ABEC 1 bearings. Because of the large differences in the facilities required for aircraft bearing production in comparison to existing U.S. facilities, it would make more sense to build a new facility, if a Japanese supplier wanted to set up production of these bearings in the United States, than to modify an existing facility. If there was a strong business reason to set up an aircraft bearing plant in the United States, Japanese suppliers would seriously consider it.

- All of the bearing companies seem to be tracking turbine engine development trends on a global basis and are keeping up with performance and quality advancements as they evolve.

- Use of the latest CNC machine tools and computer control of production processes were observed. Some postprocess inspection at the machine level was observed. However, as in the United States, inspection was not highly automated because of the small lot sizes generally involved in production. The general trend is toward more automation in all aspects of production including machining, process flow monitoring, production planning, and product design. Some use of automated guided vehicles for parts transfer between work stations and shop floor computer terminals for parts tracking, machining instructions transfer, and statistical process control data collection was observed.

- Production facilities were in general very clean and well maintained. In one facility that focused on final grind and assembly of aircraft and other high-performance bearings, definite efforts were noted at maintaining almost a "clean room" type grinding facility. Final inspection and assembly were all done in clean room environments as is typical in high-performance bearing production.

- "Just-in-time" philosophy was followed in manufacturing, resulting in very little product stored on the shop floor. Efforts to keep parts moving smoothly through production rather than waiting at a machine before the next step can be performed seemed to be quite effective.

- In terms of production, similar concerns were expressed to those most frequently mentioned by U.S. manufacturers. Among these were needs for automated surface quality inspection, simplified and more standardized marking, and nondestructive evaluation (NDE) for carburized materials.

- In the research and development area for steel bearings, the need for improved corrosion resistance for aircraft quality bearings and an interest in alternative processing techniques, including hard turning, were expressed.

- Top quality research into the origin and progression of fatigue in bearings is being conducted. In many applications, surface-initiated fatigue has been found to be more prevalent than subsurface fatigue, while to date most fatigue life theories only deal with subsurface-originated failures. This research, using x-ray and eddy current measurements, is leading toward an ability to predict the remaining life in a bearing. It has already permitted a much more detailed understanding of fatigue mechanisms to be developed and the relative importance of surface and subsurface mechanisms to be accounted for in different applications. Understanding developed from this research is being used in practical ways to improve bearing performance. A line of sealed, clean bearings for general-purpose use was developed to improve life via reduction of the probability of surface-initiated failure based on this research.

- Fatigue research shows that in cases where surface-initiated fatigue is the primary failure mode, improvements in the substrate material produce less life improvement than is found when the same improved material is used where subsurface failures are the primary life limitation. Only by reducing or eliminating surface-initiated failures can the full life potential of a bearing material be achieved.

- There was recognition of the possible need for higher temperature bearings and lubricants for advanced aircraft turbine engines including solid-lubricated ceramic bearings. However, while some very impressive work is being done in ceramic materials, to date Japanese work on solid lubrication appears to be less extensive than that in progress in the United States.

- In addition to work on ceramic bearings and solid lubrication, research was also underway on gas and magnetic bearings.

- A number of applications of hard coatings like TiN were described including one involving solid-lubricated, hard-coated, high-temperature steel races with ceramic rolling elements. Table 1 summarizes some of the more interesting applications described.

Ceramic Bearings

- All of the companies visited are in the process of testing or introducing both hybrid steel/ceramic and full ceramic bearings into the appropriate markets. Limited quantities of silicon nitride rolling element bearings have been in production over the last 2 to 4 years. One of the key suppliers of silicon nitride materials to the bearing companies is Toshiba. Komeya and Kotani (1986) (see Appendix C, Ref 2) reported that in 1975 silicon nitride powder of acceptable purity, size, and shape distribution was not commercially available. Therefore, Toshiba studied synthesis of powder. These preliminary experiments were based on a silica reduction method comprising $SiO_2 + C + N_2 \rightarrow Si_3N_4 + CO$. However, grain morphology

control was difficult. Finally good microstructural control was achieved by adding fine grains of Si_3N_4 in mixing SiO_2 + C. The result was a powder of 98 percent alpha phase. For manufacturing ceramic bearings, a powder mixture is prepared by adding 5 wt % Al_2O_3 to the α-Si_3N_4 powder. In addition to serving as a sintering aid, when α-Si_3N_4 is sintered with Y_2O_3, crystal grains are elongated and this tends to result in higher fracture toughness. Hot pressing and pressureless sintering are applicable.

- Kyocera is also developing ceramic materials for bearing applications. Some of the other companies displaying ceramic bearing components at the Nagoya Fine Ceramic Fair included: Koba; Showa Denko; Tyko, Ltd.; Kawasaki Heavy Industries; Ube; Nippon Steel; and Koba Electrics. European companies showing bearing components included: ESK (Federal Republic of Germany) and Lucas Cookson Syalon, Ltd. (United Kingdom). There were no U.S. ceramic exhibitors.

- There was a consensus that hipped Si_3N_4 is the best material for rolling element bearing performance. The materials regarded as most promising all had Al_2O_3 + Y_2O_3 additives. Data indicated that this material has higher strength than materials with MgO additives.

- In general, both races and rolling elements were produced in rough blanks shaped like the final component rather than being machined out of bulk material. While research is ongoing in near net shape forming of components, at present there is too much shrinkage and distortion during hipping to permit it. The ultimate goal of ceramic bearing development is to achieve near net shape technology, thereby reducing the machining necessary to produce a final part. Because much of the ceramic machining involves expensive diamond grinding, reducing the rough stock removal required could significantly impact the cost of ceramic components.

- Some important characteristics of bearing quality silicon nitride are given in Tables 2 to 5 and Figures 1 to 3. While Japanese researchers were aware of and interested in using ceramics with solid lubricants at elevated temperatures, the primary emphasis of the current work described involved use of either steel/ceramic hybrid bearings or all ceramic bearings with either liquid or grease lubrication.

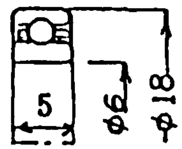
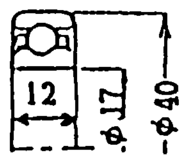
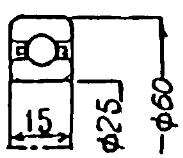
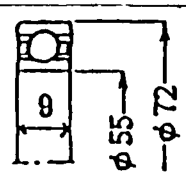
- The main incentives described for using ceramic materials in conventional applications included:

  - The lower density of the rolling elements reduces the centrifugal forces of the balls on the outer race to about 40 percent of that for steel balls. At high speeds, this can lead to a longer bearing life.

  - The low coefficient of thermal expansion permits operating with a higher thermal gradient for a given internal clearance.

  - Higher elastic modulus reduces the Hertzian contact area and lowers lubricated heat generation allowing a hybrid steel/ceramic bearing to be operated at about 20 to 25 percent higher speeds than an all steel bearing under the same lubrication conditions. Figure 4 shows comparative data for a grease-lubricated ACH016C size bearing.

Table 1. Application Examples

Item	Construction				Properties					Operating Conditions		
	Diagram (dimensions in mm)	Materials										
		Rolling Element	Inner & Outer Ring	Retainer	Heat Resistant	Corrosion Resistant	Lightweight	Self-Lubricating	Anti-Magnetic	Temperature (°C)	Speed (rpm)	Others
Turbocharger		Ceramics	Heat-Resistant Steel (SKH4)	Brass	X					10-200	200,000	Solid lubrication in the future
Gas Turbine Engine		Ceramics	Heat-Resistant Steel + Surface Treatment (SKH4 + TiN)	Heat-Resistant Material + Surface Treatment (Cr_2O_3)	X			X		350-450	50-200	Solid lubrication (no oil)
Gas Turbine Engine		Ceramics	Ceramics	Heat-Resistant Steel	X		X			20-130	1,000-10,000	500 kg
Centrifugal Separator		Ceramics	Heat-Resistant Steel + Surface Treatment (SKH4 + TiN)	Graphite	X	X		X	X	400	10,000	Solid lubrication (no oil)
Diesel Engine		Ceramics	Heat-Resistant Steel	Graphite	X			X				

Courtesy of Koyo Seiko Co., Ltd.

Table 2. Characteristics of Silicon Nitride (after Ref 2)

Item	Characteristic
Density	3.21 g/cm^3
Coefficient of thermal expansion (25–1,000 °C)	3.2 x 10^{-6} 1/°C
Thermal conductivity (RT)	29.3 W/m•k
Modulus of elasticity (RT)	3.2 x 10^4 kgf/mm^2
Poisson ratio (RT)	0.26
Three-point bending strength (Weibull modulus) (RT)	106 (15) kgf/mm^2
Hardness (RT)	1,800 kgf/mm^2
K_{IC}	~7 MPam$^{1/2}$
ΔT_C	900 °C

  - The higher elastic modulus of the rolling elements coupled with smaller internal clearance requirements due to the low ceramic thermal expansion results in a higher bearing stiffness, which permits better shaft control in high-speed spindles. Better shaft control, in turn, results in better machining accuracy.

- The capability to produce high-performance, spindle-quality, ceramic bearing components clearly exists in Japan. Some bearing suppliers also produce special spindles with hybrid ceramic bearings.

- Production numbers have reached a level where reasonable confidence has been developed that satisfactory quality ceramic components can be produced consistently. One manufacturer cited experience running life tests on "over a hundred" of both full ceramic and steel/ceramic hybrid bearings.

- A 100-hour test has been completed by IHI of an aircraft engine gearbox with 8 full ceramic bearings and 11 hybrid bearings to gain experience with their performance in a real machine. At the time of our visit, 50 hours of the test had been completed and no noticeable wear was observed. Test bearings were described as basically appearing like new.

- Recently, additional testing has been completed and close inspection of the disassembled transmission box showed fully successful results with no apparent damage.

- Efforts have been made to develop materials with crystalline grain boundaries rather than glassy ones. While this was described as desirable, it was not clear whether crystalline grain boundaries had actually been achieved in bearing-quality ceramic materials.

- Development of improved NDE methods is an important remaining requirement in the development of these materials. Toshiba is doing considerable work in this area, including work on an x-ray CT scanner for material evaluation.

- There was considerable interest in the solid-lubricated bearing research in the U.S. The ceramic suppliers in particular see solid-lubricated elevated-temperature bearings as a major future application of ceramic materials.

Table 3. Comparison Between High Carbon Chromium Bearing Steel and Silicon Nitride (after Ref 2)

Item	Silicon Nitride	High Carbon Chromium Bearing Steel
Heat-resistant temperature, °C	800	120
Corrosion resistance	Large	Small
Specific gravity	3.2 or above (small centrifugal force of roller)	7.8 (large centrifugal force of roller)
Hardness Hv (room temperature)	1,800 - 2,000	700 - 800
Friction without lubrication	Small	Large
Magnetic property	Nonmagnetic	Magnetic
Rigidity (Young's modulus), kgf/mm^2	32,000	21,000

Table 4. Accuracy of Silicon Nitride Ball (after Ref 2)

Item	Developed Material	Comparison Material
Sphericity, µm	0.3	0.5
Surface roughness Ra, µm	0.006-0.008	0.04-0.08

CONCLUSIONS

- Bearing suppliers in Japan are strong world-wide corporations that are intent upon developing their business on an international basis.
- The aircraft and precision bearing facilities visited were clean and modern with primarily new and up-to-date machinery. However, no radical differences were seen in the basic approaches used in manufacturing as compared to U.S. companies.
- A strong philosophy that each worker was responsible for the precision and quality of his operation was in evidence. There didn't seem to be the split between production and quality control sometimes seen in U.S. companies.
- Great pride was taken in the use of quality circles and improving quality via input from the workers actually producing the parts.

Table 5. Characteristics of Ceramic Fatigue by Conventional Theory (after Ref 1)

Item	Ceramic Fatigue	Metal Fatigue
Mechanism	By mechanochemical reaction between stress and moisture	By accumulation of alternative microscopic plastic deformation
Dependence	Time dependent	Cycle dependent
Stress Factor	1st: Tensile stress. No effect: Stress amplitude; frequency; compressive stress	1st: Stress amplitude. 2nd: Mean stress; frequency
Material Factor	Glass and alumina suffer; nonoxide ceramics hardly suffer	All metals suffer
Environmental Factor	Moisture is indispensable	Corrosive environment can accelerate

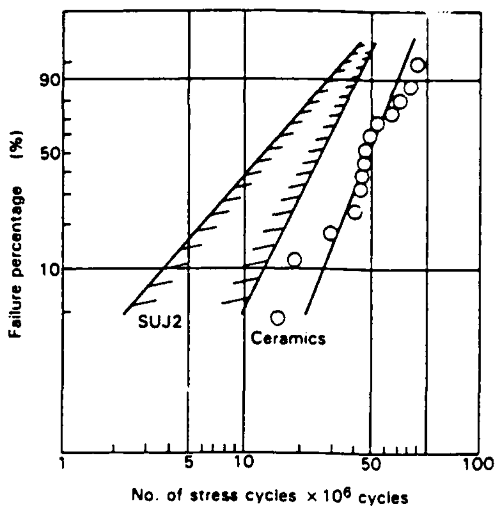


Figure 1. Rolling fatigue life of silicon nitride (from Ref 2).

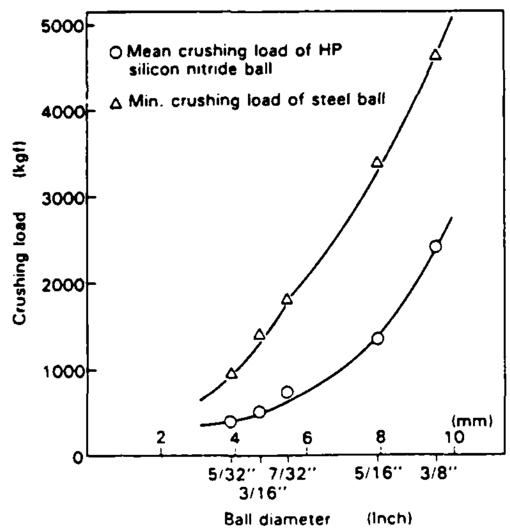


Figure 2. Crushing load comparison between silicon nitride ball and steel ball (from Ref 2).

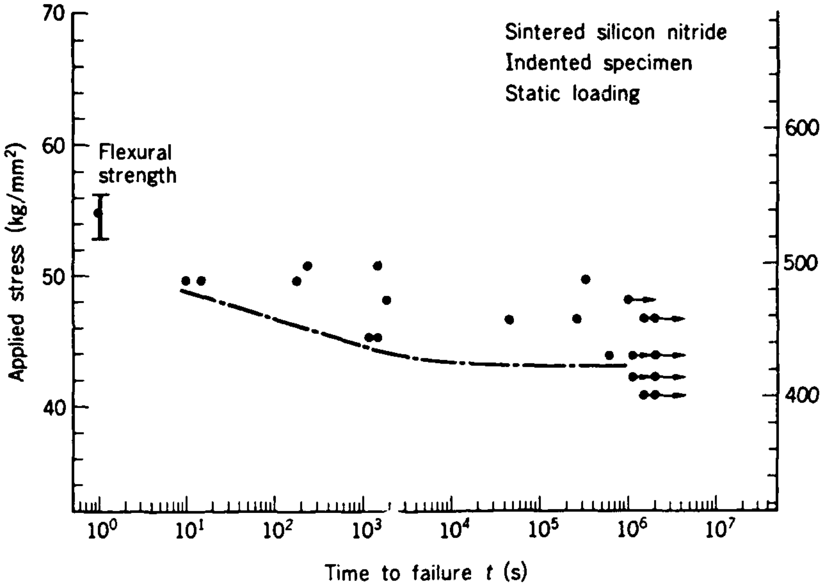


Figure 3. Static fatigue life of sintered silicon nitride (from Ref 1).

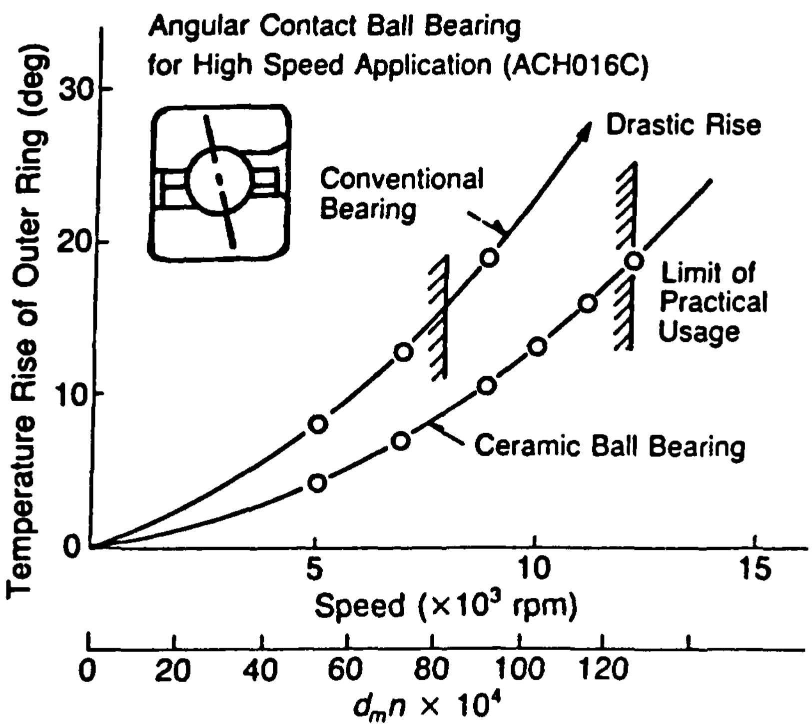


Figure 4. Test results under high speed rotation (courtesy of Koyo Seiko Co., Ltd.).

- The use of charts displayed at different places throughout the plant showing how each different department's efforts fit in the overall process was felt to give workers a better sense of the final product. Department production rates and reject rates were also posted to remind the workers of the goal of zero defects.

- Considerable high-quality research in rolling element bearing technology is in progress in Japan. Benefits could be realized by U.S. suppliers by following Japanese research as closely as possible.

- In terms of ceramic materials and ceramic bearing production for liquid- and grease-lubricated applications, the Japanese appear to be ahead of the United States. However, considerably less solid lubrication research was evident in Japan when compared to the United States.

- All of the Japanese companies visited were open about their capabilities and our visits were hosted by top level management. A genuine willingness to cooperate was felt in our visits.

- If Japanese suppliers could be shown that there is a U.S. market that justified the investment, they would consider developing aircraft or ceramic bearing facilities in the United States. Any such assessment would include both market potential and competition.

- In general-purpose bearings, third world and developing countries like Singapore and Korea are becoming strong competition for Japanese suppliers.

James F. Dill received B.S. and M.S. degrees in physics from John Carroll University and a Ph.D. in physics/chemical engineering from Catholic University of America. Currently Dr. Dill is the manager of the Technology Development Branch at the R&D Division of Mechanical Technology Inc. He is responsible for the analytical and experimental programs in bearings, seals, gearing, rotordynamics, and basic tribology. He also acts as a consultant on bearing and lubricant technology. Dr. Dill's areas of interest are rolling element bearings, bearing materials, chemical physics of lubricants, rotordynamics, and experimental design and instrumentation. He is a member of the American Society of Lubrication Engineers, the American Society of Mechanical Engineers Research Committee on Tribology, and the North American Society of Adlerian Psychology.

Robert A. Harmon received B.S. and M.S. degrees in mechanical engineering from the Illinois Institute of Technology. Mr. Harmon has over 38 years of experience in applied research and program development at International Harvester, IITRI (formerly ARF), Williams International, General Electric Company, and Mechanical Technology, Inc. As an independent consultant since 1970, he has focused on gas turbines; diesel engines; and combined cycle power and cogeneration systems for industrial, marine, and vehicle applications. His emphasis has been on identification of the research and development needed to fill technology gaps and advance the state-of-the-art for critical components. Hence, he has recently focused on advanced materials such as ceramics and composites. Mr. Harmon has been active on numerous Society of Automotive Engineers and American Society

of Mechanical Engineers (ASME) technical committees, the International Organization for Standardization TC 70 Committee, and the American National Standards Institute B133 Committee. He was chairman of the ASME Gas Turbine Division in 1966.

Edward Mark Lenoe, on leave from the Army Materials and Mechanics Research Center, joined the staff of ONRFE/AFOSRFE/AROFE in October 1985. Previously he managed the AMMRC Reliability Mechanics and Standardization Division, served as operating agent for the International Energy Agency implementing agreements on high temperature ceramics for heat engine applications, and also managed numerous major contracts. His studies for ARO will be devoted to structural ceramics.

Appendix A

VISITING PERSONNEL

Mechanical Technology Inc. (MTI):

*Dr. James F. Dill, Technical Director
MTI Bearing Tech Mod Program

Robert A. Harmon, Consultant

Air Force:

Carl A. Lombard, Tech Mod Director

Cheryl A. Jones, Tech Mod Project Manager

Office of Naval Research, Liaison Office Far East:

**Dr. Edward M. Lenoe, Liaison Scientist

Army Material Command, Science and Technology Center Far East:

**Joey F. Crider, Materials Engineer

**Junya Suda, Coordinator

**Sadao Saito, Coordinator

---

*Team leader.

**Did not attend all visits.

Appendix B

COMPANY PERSONNEL

Nippon Seiko K.K. (NSK) at Fujisawa

Dr. Seiho Yamamoto, Managing Director
Bearing Technology

Minoru Akiyama, Director
Bearing Technology

Dr. Kazuo Kakuta, Director
General Manager, Research and Development
Manager, Tribology Research and Development

Hiroshi (Harry) Mitsuhashi, Senior Manager
Aerospace Group, Precision Bearing Technical Center

Keiji Takada, Senior Project Engineer
Bearing Engineering Division

Dr. Satoru Aihara, Senior Researcher
Manager, R&D Center

Katsuya Touma, Manager 2nd Department
Tribology, Research and Development

Mr. Abe, Assistant General Manager
Materials R&D

Y. Kosaka, No. 1 Plant Manager at Fujisawa

Mr. S. Saitoh, Manager
Precision Bearing Section of No. 1 Plant at Fujisawa

Koichi Takano, Manager
Marketing Department – America

NSK, Otsu Plant

Reijirou Hosokawa, Director Factory Manager
Nippon Seiko Co., Ltd.

Kazuo Harashima, Product Engineering Manager
Nippon Seiko Co., Ltd.

Nobutaro Nakagawa, Production Manager
(Machining & Heat Treatment)
Nippon Seiko Co., Ltd.

Setsuo Ueno, Quality Assurance Manager
Nippon Seiko Co., Ltd.

Koyo Seiko Co., Ltd., Kokubu Plant

Ikuro Ito, Executive Director

Saburo Ueno, Managing Director
Engineering Department

Kanji Ogura, Managing Director
R&D Division

Toshio Miki, Director
Engineering Department

Akira Nomura

Mr. H. Yasui, General Manager
Research and Development Dept. 1

Mr. H. Kotani, Deputy General
Manager, Research and Development Dept. 1

Mac Yokoyama, Senior Engineer
Overseas Coordination Dept.

NTN Toyo Bearing Co., Ltd., Kuwana Plant

M. Takimoto, Manager
Aerospace Bearing Operations Department

K. Yamashita, Manager
Technical Department

Tomosaburo Ogiuchi, Manager
Export Department International Trade
Headquarters

Noriyuki Tsushima, Ph.D.
Manager, Research Section
Product Research Department
Engineering Headquarters

M. (Mike) Tajiri
Senior Design Engineer
Design Section
Technical Department
Aerospace Bearing Headquarters

Toshiba, New Materials Department, Yokohama

Dr. Katsutoshi Komeya
Senior Manager
New Materials Department

Katsutoshi Nishida
Senior Specialist
New Materials Department

Koichi Inoue, Engineer
New Materials

Kyocera Corporation, Kyoto

Y. Hamano, Dr. Engineering
Senior Managing Director
General Manager
Corporate Planning Division

Dr. Kazunori Koga
Materials Development Division

Mataro Miyazaki, Manager
Automotive Components

Ishikawajima–Harima Heavy Industries Co. (IHI)

Chiaki Aoki, Vice President
Aero–Engine & Space Operations

Dr. Shinobu Saito, Section Manager
Machinery Department
Research Institute

Y. Yamashita, Manager
Precision Gears Engineering Group
Aero–Engine & Space Operations

Seiji Kobayashi
F–3 Engine Project Department
Aero–Engine Division
Aero–Engine & Space Operations

Appendix C

LIST OF REFERENCES

1. T. Kawakubo and A. Goto, Fatigue strength analysis of silicon nitride, Toshiba Review No. 158 (Toshiba R&D Center, winter 1986), pp. 39–42.

2. K. Komeya and H. Kotani, "Development of ceramic antifriction bearing," Japan Society of Automotive Engineers Review 7 (3), 72–79 (October 1986).

3. Y. Tanimoto, M. Fujii, and H. Mizuguchi, X-ray nondestructive inspection using digital image processing, Toshiba Review No. 156 (Toshiba R&D Center, summer, 1986), pp. 15–20.

4. K. Touma, H. Kawamura, and K. Kawakita, "Ball motion in high speed angular contact ball bearings," paper presented at Japan Society of Lubrication Engineers International Tribology Conference, 8–10 July 1985 (paper no. 601901).

5. N. Tsushima, H. Nakashima, and H. Kashimura, "Various types of bearing failures," paper presented at the Society of Automotive Engineers Earthmoving Industry Conference, Peoria, April 1987 (SAE paper no. 870797).

6. N. Tsushima, H. Yamada, and K. Maeda, "Changes in x-ray parameters with loading cycles in rolling contact in various through hardened bearing steels," paper presented at American Society of Lubrication Engineers Annual Meeting, 1987.

7. W. Wade et al., "A structural ceramic diesel engine - The critical elements," Society of Automotive Engineers, February 1987 (SAE paper no. 870651). Koyo Seiko participated with a roller bearing test rig simulating crankshaft main bearing loads and speeds to test silicon nitride roller bearings.

THE INDIAN CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

Wayne V. Burt

The Central Marine Fisheries Research Institute was established to conduct research to improve exploitation, management, and conservation of marine and brackish water fisheries resources. This article describes the institute's efforts to improve the culture of prawns; sea weed; pearls; mussels, oysters, and clams; fin fish, lobsters and crabs; and marine turtles.

PROLOGUE

India is chronically in need of increasing its supplies of food for its burgeoning population. Its present yield of marine fisheries products within the 0- to 50-meter depth zone is only 15 percent of an estimated potential yield of just over 2 million tons a year. There is an additional potential yield of over 2 million tons per year in the deeper waters running out to the edge of the 200-mile exclusive economic zone with even a smaller percentage of present yield. Of 135,000 fishing vessels in India, less than 20,000 are motorized. There is a good deal of need for research to increase fisheries technology and improve fisheries management in order to increase the sustained yield of marine fisheries products.

The history of freshwater aquaculture in India dates back to 300 B.C. On the other hand, mariculture, the culture of marine fish and other marine organisms, is of much more recent origin. India abounds in brackish lakes, estuaries, backwaters, and coastal mangrove and other swampy coastal areas. Recent estimates state that there are over 4 million acres near the coasts that are suitable for mariculture of one sort or another. However, only 74,000 acres, less than 2 percent, are now being used for mariculture.

The above facts indicate that there is a wide open field for marine fisheries and mariculture research.

FISHERIES AND MARICULTURE RESEARCH

The Central Marine Fisheries Research Institute was established in February 1947 by the Government of India within the Ministry of Agriculture and Irrigation. It later came under the control of the Council of Agricultural Research.

The objectives of the institute are to conduct research related to the marine fisheries and mariculture in order to improve exploitation, management, and conservation of marine and brackish water fisheries resources and to support development and stability to all facets of the industry through transfer of technology and dissemination of information through education, training, and extension programs.

The headquarters and main laboratories of the institute are in a 1-year-old, five-story building with 91,000 ft^2 of floor space. The building is located on the waterfront of one of the channels of the main estuary in Cochin in the long, narrow State of Kerala on the southwest coast of India.

In addition to the headquarters, there are 12 other research centers belonging to the institute scattered around the coast of India and 29 field centers along the coasts of India that collect fisheries catch data and other relevant statistics. The institute has a staff of 300, including 60 scientists.

PRAWN CULTURE

Many of the estuaries in southern India have numerous islands near their mouths with channels other than the main river channel between the islands. The areas between the islands are called backwaters. Most of the mariculture takes place in these backwaters. For centuries prawns have been cultured in these areas. During the postmonsoon season, the backwaters are brackish with a mixture of salt and fresh waters. Earthen or stone bunds or dikes separate many of the backwaters into paddies. During high water these paddies are flooded and prawns in various stages of growth are captured in the fields. The weirs separating the paddies from the tidal channels are screened to keep the shrimp from escaping but allowing the tides to bring in food organisms for the shrimp. The yields are poor and uncertain.

Before the monsoon season arrives the shrimp are harvested. When the monsoon rains begin the fields are flushed out with freshwater from the runoff. Then a crop of rice is grown during the monsoon season.

The institute has done a tremendous amount of work to improve the mariculture of shrimp. Hatcheries where prawn "seeds" are hatched and grown by the millions have been developed and improved. Methods to manipulate the female prawns so they will spawn on demand as well as methods of artificial insemination that have increased the hatching rate of prawn eggs in the hatchery from 3 to over 90 percent have been developed. This enables the prawn farmer to seed his paddy with young prawns that are all the same age and can be harvested all at the same time. One of the most important things that the hatcheries can do is select the best species of shrimp to grow in paddies. The ideal salinity range for this species ranges from 10 to 35 ppt. If a farmer follows all of the procedures recommended by the institute, he can harvest a little over a quarter of a ton of shrimp per acre in just under 2 months and raise several crops each year. The shrimp that are cultured are strictly a cash crop. The shrimp bring such a good price that the farmers and their families cannot afford to eat them.

SEA WEED CULTURE

Some species of sea weeds are a much needed raw material for obtaining agar-agar, algin, and pharmaceutical chemicals. The institute has developed a simple technology for culturing commercially important sea weeds. The method involves growing fragments of fresh seaweed on coir rope made from coconut husks. The growth increases the amount of sea weed by 400 or 500 percent. Three harvests or crops can be taken in a year.

PEARL CULTURE

Hatchery techniques have been developed for breeding of pearl oysters and rearing their larvae to young pearl oysters suitable for transplanting to open sea farms. About 60 to 70 percent of the nucleus-implanted oysters produce pearls in from 3 to 24 months, depending on the size of the pearls.

CULTURE OF MUSSELS, OYSTERS, AND CLAMS

The institute has developed viable technologies for open-sea farming of mussels, farming of edible oysters in the backwaters and creeks, and culturing of clams in open bays. All three are now bred in hatcheries and their larvae are reared in the hatcheries until they are old enough to be transported to the habitat where they will grow to adult size.

FIN FISH CULTURE

The institute has shown that milk fish, mullets, whiting, and perches can be profitably grown in pens and cages and even in polyethylene-lined ponds in beaches with proper management techniques.

LOBSTERS AND CRABS

Breakthroughs have been achieved in the rearing of lobsters and in the breeding and culturing of crabs. These crustaceans bring a good price and have good mariculture potential for the coastal waters of India.

MARINE TURTLES

Predators, including man, take a heavy toll on the marine turtles that come ashore to lay their eggs in the sand of beaches. Every year the institute gathers several hundred turtle eggs and hatches them out and sees that the young are safely placed in the ocean. This helps to ensure that, while the turtles are an endangered species, they will not eventually become extinct.

EDUCATION

A Center for Advanced Studies in Mariculture was established at the institute in 1979 under the sponsorship of the Indian Council of Agricultural Research, the United Nations Development Program, and the United Nations Food and Agricultural Organization.

Although the specific technologies for the culture of many commercially important marine organisms have become available, a prospective market for the produce is waiting, and financing is available, a sufficient number of trained people have not been available to guide and execute mariculture programs. This constraint was found to seriously hamper the development and expansion of mariculture projects. To correct this program, a Master of Science program in mariculture was established at the institute. It is a 2-year program. Ten new students are accepted each year. In addition to course work, the students are required to gain practical experience through laboratory and field work and to know basic research techniques.

The Ph.D. degree is also offered to more advanced research-oriented students. It is a 3-year program and again 10 new students are admitted to the program each year.

Under the Lab-to-Land program the actual technologies are carried to the farmers' fields, where institute scientists help the farmers with their mariculture problems. Some 500 families have been helped in this way. Short courses, seminars, and radio programs are all used to give information to the farmers. Detailed manuals giving all the specifics have been written on hatchery production of prawn seed and on prawn farming in Kerala.

The institute renders consultancy services to small farmers, fish culturists, the industry, development agencies, and government departments on various aspects of capture fisheries, mariculture, and environmental problems.

The research and instructional programs in the institute are most impressive. All of the people that I interviewed spoke good English and the scientific papers given to me were all in English. I believe that it would be worthwhile to send a few American students to the institute for training in mariculture techniques.

The address of the institute is: Central Marine Fisheries Research Institute, Post Bag No. 2704, Cochin - 682 031.

INTERNATIONAL MEETINGS IN THE FAR EAST

1988–1994

Compiled by Yuko Ushino

Yuko Ushino is a technical information specialist for ONR Far East. She received a B.S. degree from Brigham Young University at Provo, Utah.

The Australian Academy of Science, the Japan Convention Bureau, and the Science Council of Japan are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

1988

Date	Title, Attendance	Site	For information, contact
January 28-31	Royal Australian Chemical Institute, Division of Inorganic Chemistry, National Meeting (COMO 13)	Melbourne, Australia	Dr. P. Tregloan, Department of Inorganic Chemistry, University of Melbourne Parkville, Victoria 3052
February 2-5	The International Association of the Institute of Navigation (IAIN) Congress	Sydney, Australia	The Australian Institute of Navigation Box 2250, G.P.O., Sydney, New South Wales, Australia 2001
February 2-5	A Congress of the International Association of Institutes of Navigation	Sydney, Australia	Professor Günther Zade, World Maritime University P.O. Box 500, S-20124 Malmö, Sweden
February 22-26	Engineering Conference	Sydney, Australia	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
February (tentative)	The 10th Australian Electron Microscopy Conference	(Undecided)	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
March 1-3	International Forum on Fine Ceramics '88 Nagoya Japan 10-F100-J900	Nagoya, Japan	Secretariat: International Forum on Fine Ceramics c/o Japan Fine Ceramics Center 2-4-1 Mutsuno, Atsuta-ku, Nagoya 456

*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.

No. of participating countries
F: No. of overseas participants
J: No. of Japanese participants

Date	Title, Attendance	Site	For information, contact
March 10-12	International Biotechnology Symposium '88 (tentative) 10-F100-J500	Nagoya, Japan	Organizing Committee of International Biotechnology Symposium c/o The Foundation of Chubu Science and Technology Center 2-17 Sakae, Naka-ku, Nagoya 460
March 14-16	International Symposium on Non-Equilibrium Solid Phase of Metals and Alloys F100-J200	Kyoto, Japan	Department of Metal Science and Technology, Faculty of Engineering, Kyoto University Yoshida-hommachi, Sakyo-ku, Kyoto 600
March 14-17	International Symposium on Non-Equilibrium Solid Phases of Metals and Alloys N.A.-F100-J200	Kyoto, Japan	Department of Metal Science and Technology, Faculty of Engineering, Kyoto University Yoshida-Hommachi, Sakyo-ku, Kyoto 600
March 22-25	International Symposium on Basic Technology for Future Industries (New Materials) 6-F15-J700	Kobe, Japan	c/o Agency of Industrial Science and Technology Ministry of International Trade and Industry 2-1-3 Kasumigaseki, Chiyoda-ku, Tokyo 100
March 22-26	International Conference on Several Complex Variables, Kyoto 7-F15-J26	Kyoto, Japan	Research Institute for Mathematical Sciences, Kyoto University Oiwake-cho, Kita-Shirakawa, Sakyo-ku, Kyoto 606
April 4-12	The 4th International Conference on Aluminium Association (JLWA) 32-F100-J150	Tokyo, Japan	Japan Light Metal Welding and Construction Weldment Yura Building, 3-37-23, Kanda-Sakumacho, Chiyoda-ku, Tokyo 101
April 11-14	ISFNT International Symposium on Fusion Nuclear Technology 20-F150-J50	Tokyo, Japan	Nuclear Engineering Research Laboratory, Tokyo University Tokai-mura, Naka-gun, Ibaraki 319-11
April 13-15	The 21st JAIF Annual Conference 25-F250-J1,000	Tokyo, Japan	Japan Atomic Industrial Forum, Inc. Koshin Building, 1-1-13 Shimbashi, Minato-ku, Tokyo 105
April 19-23	International Conference on Nuclear Power Plant Water Chemistry-Operation Experience and Sophisticated Management Technology	(to be decided)	Japan Atomic Industrial Forum, Inc. Toshin Building, 1-1-23 Shimbashi, Minato-ku, Tokyo 105

1988

Date	Title, Attendance	Site	For information, contact
April 26- May 3	The 3rd World Biomaterials Conference 15-F500-J500	Kyoto, Japan	Japan Society for Biomaterials c/o Institute for Medical and Dental Engineering, Tokyo Medical and Dental University, 2-3-10 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
May 13-15	International Symposium on Advanced Thermal Spraying Technology and Allied Coatings 13-F50-J150	Osaka, Japan	High Temperature Society of Japan c/o Welding Research Institute of Osaka University 11-1 Mihogaoka, Ibaraki-shi, Osaka 567
May 16-20	The 4th International Conference on Metalorganic Vapor Phase Epitaxy	Hakone, Japan	Professor T. Katoda, Secretary, ICMOVPE IV c/o International Congress Service, Inc., Kasho Building 2F, 2-14-9 Nihombashi Chuo-ku, Tokyo 103
May 22-27	The 16th International Symposium on Space Technology and Science	Sapporo, Japan	The 16th International Symposium on Space Technology and Science, Sapporo Organizing Committee 4-6-1 Komaba, Meguro-ku, Tokyo 151
May 25-27	The 5th International Microelectronics Conference (IMC 1988)	Tokyo, Japan	Dr. H. Hirabayashi, ISHM Japan Chapter 6-20-4 Hanakoganei, Kodaira-city, Tokyo 187
May 29- June 2	The 5th International Symposium on Halide Glasses	Susono, Japan	Professor Masayuki Yamane, Inorganic Materials, Faculty of Engineering, Tokyo Institute of Technology 2-12-1 Ookayama, Meguro-ku, Tokyo 152
May 30- June 3	MRS International Meeting on Advanced Materials 20-F600-J1,500	Tokyo, Japan	Organizing Committee for MRS International Meeting on Advanced Materials c/o Nikkan Kogyo Shimbun Ltd., Planning Bureau, 1-8-10 Kudan-kita, Chiyoda-ku, Tokyo 102
May 30- June 3	International Conference on Nuclear Data for Science and Technology 10-F100-J200	Mito, Japan	Japan Atomic Energy Research Institute Tokai-mura, Naka-gun, Ibaraki 319-11

1988

Date	Title, Attendance	Site	For information, contact
June 5-6	The 7th International Conference on Ion Implantation Technology (IIT'88) - Technical School	Kyoto, Japan	Professor Isao Yamada, Ion Beam Engineering Experimental Laboratory, Kyoto University Sakyo, Kyoto 606
June 5-10	The 6th International Conference on Surface and Colloid Science	Hakone, Japan	Division of Colloid and Surface Chemistry, The Chemical Society of Japan 1-5 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
June 6-10	International Conference on Physical Metallurgy of Thermomechanical Processing of Steels and Other Metals 20-F100-J100	Tokyo, Japan	Nippon Tekko Kyokai 3rd Floor, Keidanren Kaikan, 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100
June 7-10	International Conference on Precision Electro-magnetic Measurements (CPEM'88)	Tsukuba, Japan	The Society of Instrument and Control Engineers 1-35-28-303 Hongo, Bunkyo-ku, Tokyo 113
June 7-10	The 7th International Conference on Ion Implantation Technology (IIT'88)	Kyoto, Japan	Professor Isao Yamada, Ion Beam Engineering Experimental Laboratory, Kyoto University Sakyo, Kyoto 606
June 12-17	The International Conference on Ion Beam Modification of Materials (IBMM'88)	Tokyo, Japan	Professor Susumu Nanba, Faculty of Engineering Science, Osaka University 1-1 Machikaneyama-cho, Toyonaka-city, Osaka 560
June 13-15	JSAP-MRS (Japan Society of Applied Physics-Material Research Society) International Conference on Electronic Materials	Tokyo, Japan	Professor Takeshi Kamiya, Faculty of Engineering, Tokyo University 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
June 23-24	The 3rd Asia Pacific Physics Conference	Hong Kong	K. Young, Secretary, Local Organizing Committee, The 3rd Asia Pacific Physics Conference c/o Department of Physics, The Chinese University of Hong Kong, Shatin, Hong Kong
July 1-12	The 16th International Congress of Photogrammetry and Remote Sensing 48-F2,000-J2,600	Kyoto, Japan	Japan Society of Photogrammetry 601 Daiichi Honan Building, 2-8-17 Minami-Ikebukuro, Toshima-ku, Tokyo 171

1988

Date	Title, Attendance	Site	For information, contact
July 12-15	The 6th International Conference on Ultrafast Phenomena 20-F200-J200	Shiga, Japan	The 6th International Conference on Ultrafast Phenomena Organization Committee c/o OPTO Marketing Service Ltd., Maenocho Heights 5-206, 6-10 Maenocho, Itabashi-ku, Tokyo 174
July 17-23	International Congress of Endocrinology 48-F2,000-J2,600	Kyoto, Japan	Japan Endocrine Society c/o Seirenkaikan, Kyoto Furitsu Medical University, Nishizume Konjinbashi, Kamigyo-ku, Kyoto 602
July 18-22	International Symposium on Scale Modeling	Tokyo, Japan	Secretariat: c/o The Japan Society of Mechanical Engineers, Sanshin Hokusei Building, 2-4-9 Yoyogi, Shibuya-ku, Tokyo 151
July 18-22	1988 XVI International Conference on Quantum Electronics 30-F300-J700	Tokyo, Japan	Optoelectronic Industry and Technology Development Association No. 20 Mori Building, 2-74 Nishi-shimbashi, Minato-ku, Tokyo 105
July 25-30	International Conference on Clustering Aspects in Nuclear and Subnuclear Systems 31-F150-J150	Kyoto, Japan	Dr. K. Tanaka, Faculty of Science, Hokkaido University 5-chome, Kita 10-jo, Kita-ku, Sapporo 060
August 1-5	The 10th Congress of the International Ergonomics Association	Sydney, Australia	Secretariat IEA88 IEA88 PO Box 380 Spit Junction, NSW 2088, Australia
August 1-6	The IUPAC 32nd International Symposium on Macromolecules 50-F600-J1,200	Kyoto, Japan	The Society of Polymer Science, Japan 5-12-8 Ginza, Chuo-ku, Tokyo 104
August 2-6	The 9th World Conference on Earthquake Engineering 59-F800-J2,000	Tokyo, Jappan	Secretariat: The 9th SCEE Steering Committee c/o Association for Earthquake Disaster Prevention 5-26-20 Shiba, Minato-ku, Tokyo 108
August 14-19	The 10th International Congress on Rheology	Sydney, Australia	R. I. Tanner, Department of Mechanical Engineering, University of Sydney NSW 2006

1988

Date	Title, Attendance	Site	For information, contact
August 15-17	International Federation of Automatic Control Symposium	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 15-17	Electrical IFAC Conference	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 15-19	The 3rd International Phycological Congress	Melbourne, Australia	Dr. M. N. Clayton, Botany Department, Monash University Clayton, Victoria 3168
August 16-19	The 7th International IUPAC Symposium on Mycotoxins and Phycotoxins 38-F100-J200	Tokyo, Japan	Japan Association of Mycotoxicology, Science University of Tokyo c/o Science University of Tokyo, 12 Fungagawara-machi, Ichigaya, Shinjuku-ku, Tokyo 160
August 21-26	International Geographical Congress	Sydney, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
August 22-26	The 5th Australia-New Zealand Conference on Geomechanics	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600
August 29-September 2	The 3rd International Conference on Synchrotron Radiation Instrumentation (SRI-88)	Tsukuba, Japan	Katsuki Kobayashi, Photon Factory Synchrotron Radiation Research Facility, National Laboratory for High Energy Physics 1-1 Uehara, Oho-machi, Tsukuga-gun, Ibaraki 305
August 30-September 2	The 5th International Conference on Molecular Beam Epitaxy 15-F150-J400	Sapporo, Japan	Japan Society of Applied Physics c/o Department of Physical Electronics, Tokyo Institute of Technology 2-12-1, Oh-okayama, Meguro-ku, Tokyo 152
September 5-8	The 1st International Conference on Computational Methods in Flow Analysis F250-J300	Okayama, Japan	Okayama University of Science 1-1 Ridaicho, Okayama 700

1988

Date	Title, Attendance	Site	For information, contact
September 19-22	The 29th International Conference on the Biochemistry of Lipids 39-F100-J200	Tokyo, Japan	Secretariat: The 29th International Conference on the Biochemistry of Lipids c/o Department of Psychological Chemistry and Nutrition, Faculty of Medicine, University of Tokyo 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
September 20-22	The 4th Japanese-German Joint Seminar on Non-destructive Evaluation and Structural Strength of Nuclear Power Plant 1-F30-J70	Kanazawa, Japan	Japan Atomic Energy Research Institute Tokai Establishment Tokai-mura, Naka-gun, Ibaraki 319-11
October 11-14	The 4th International Workshop on Electro-luminescence	Tottori, Japan	Dr. Hiroshi Kobayashi, Department of Electronics, Faculty of Engineering, Tottori University Koyama, Tottori 680
October 17-20	The 9th International Conference on Pattern Recognition	Beijing, People's Republic of China	9 ICPR Secretariat: Chinese Association of Automation P.O. Box 2728, Beijing
October 24-26	The 1st International Conference New Diamond Forum	Tokyo, Japan	Secretariat: International Congress Service, Inc. Kasho Building 2F, 2-14-9 Nihonbashi, Chuo-ku, Tokyo 103
October 24-28	The 3rd International Conference on Surface Engineering	Tokyo, Japan	Cotec Corporation Sankocho Building 5-17-14 Shinjuku, Shinjuku-ku, Tokyo 160
October 25-28	International Conference on Materials and Process Characterization for VLSI (ICMP'88)	Shanghai, People's Republic of China	Zhu Ye, Institute of Materials Science, Fudan University, Shanghai
November 2-5	International High-Performance Vehicle Conference	Shanghai, People's Republic of China	Ship Design Committee CSNAME P.O. Box 3053, Shanghai
November 8-12	The 2nd International Conference on Formulation of Semiconductor Interface (ICFSI-88)	Takarazuka, Japan	Tsunemasa Taguchi, Faculty of Engineering, Osaka University 2-1 Yamadaoka, Fukita-shi, Osaka 565

1988

Date	Title, Attendance	Site	For information, contact
November 14-17	The 3rd International Topical Meeting on Nuclear Power Plant Thermal Hydraulics and Operations	Seoul, Korea	Dr. Jong Hee Cha, P.O. Box 7 Daeduk-Danji, Choong-Nam, Korea 300-31
November 14-18	1988 Annual Meeting of the International Society for Interferon Research 35-F300-J500	Kyoto, Japan	The 5th ISIR Organizing Committee c/o Inter Group Corporation Shohaku Building, 6-23 Chayamachi, Kita-ku, Osaka 530
November 19-26	The 13th International Diabetes Federation Congress 20-F80-J120	Sydney, Australia	Professor J. R. Turtle, Professor of Medicine Department of Endocrinology, University of Sydney NSW 2006

1989

Date	Title, Attendance	Site	For information, contact
April 3-5	International Symposium for Electromachining 16-F100-J300	Nagoya, Japan	Institute of Industrial Science, University of Tokyo 7-22-1 Roppongi, Minato-ku, Tokyo 106
April 10-13	The International Symposium for Electromachining 15-F100-J300	Undecided	The Institute of Electrical Engineers of Japan Gakkai Center Building, 2-4-16 Yayoi, Bunkyo-ku, Tokyo 113
April 11-14	International Symposium on Ship Resistance and Powering Performance (ISRP)	Shanghai, People's Republic of China	International Symposium on Ship Resistance and Powering Performance Department of Naval Architecture and Ocean Engineering, Shanghai Jiao Tong University, Shanghai
April 18-21	The 2nd Asian Fisheries Forum 30-F150-J150	Tokyo, Japan	Secretariat: The 2nd Asian Fisheries Forum c/o Faculty of Agriculture, Tokyo University 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113
July 2-7	XXVII International Conference on Coordination Chemistry	Brisbane, Australia	Professor Clifford J. Hawkins, Department of Chemistry, University of Queensland Saint Lucia, Brisbane, Queensland 4067

1989

Date	Title, Attendance	Site	For information, contact
July 24-25	The 2nd Microoptics Conference/The 9th Topical Meeting on Gradient-Index Imaging Systems (MOC/GRIN '89)	Tokyo, Japan	
July	The 4th International Organization of Plant Biosystematists (IOPB) Symposium 20-F,J250	Kyoto, Japan	IOPB Symposium c/o Department of Botany, Faculty of Science, Kyoto University Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606
August 13-18	Solar Energy Congress Tokyo 1989 40-F600-J400	Tokyo, Japan	Japanese Section of International Solar Energy Society 322 San Patio, 3-1-5 Takada-no-baba, Shinjuku-ku, Tokyo 160
August 27-September 1	The 5th International Symposium on Microbial Ecology (5th ISME) 73-F600-J600	Kyoto, Japan	Japanese Society of Microbial Ecology c/o Inter Group Corporation 8-5-32 Akasaka, Minato-ku, Tokyo 107
September 5-8	Solar World Congress 1989 60-F600-J400	Kobe, Japan	Japanese Section of International Solar Energy Society, Japan Solar Energy Society 322 San Patio, 3-1-5 Takada-no-baba, Shinjuku-ku, Tokyo 160
September 8-10	1989 International Symposium on Electromagnetic Compatibility 20-F150-J350	Nagoya, Japan	Secretariat: International Symposium on Electromagnetic Compatibility c/o Department of Information and Computer Sciences, Toyohashi University of Technology 1-1 Tenpaku-cho, Aza-Hibarigaoka, Toyohashi, Aichi 440
September 24-28	The 6th International Symposium on Passivity - Passivation of Metals and Semiconductors	Sapporo, Japan	Dr. Norio Satoh, Faculty of Engineering, Hokkaido University Nishi 8-chome, Kita 13-jo, Sapporo-shi 060
October 3-5	The 10th Meeting of World Society for Stereotactic and Functional Neurosurgery 20-F200-J300	Maebashi, Japan	Department of Neurosurgery, Gumma University, School of Medicine 3-39 Showa-machi, Maebashi 371
October (tentative)	Specialty Electric Conference	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

1989

Date	Title, Attendance	Site	For information, contact
1989 (tentative)	International Conference Evaluation of Materials Performance in Severe Environments-Evaluation and Development of Materials in Civil and Marine Uses 20-F80-J120	Japan (undecided)	International Conference Secretariat, Conference and Editorial Department, Iron and Steel Institute of Japan 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100
1989 (tentative)	International Conference on Zinc and Zinc Alloy Coated Sheet Steels 20-F50-J150	Japan (undecided)	International Conference Secretariat, Conference and Editorial Department, Iron and Steel Institute of Japan 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100

1990

Date	Title, Attendance	Site	For information, contact
May 19-26	The 27th International Navigation Congress 60-F500-J500	Japan (undecided)	Japan Organizing Committee for 27th International Navigation Congress 2-8-24 Chikko, Minato-ku, Osaka 552
July (tentative)	The 10th International Congress of Nephrology 10-F1,000-J4,000	Osaka, Japan	Japanese Society of Nephrology c/o 2nd Department of Internal Medicine, School of Medicine, Tokyo 173
August 21-29	International Congress of Mathematicians	Kyoto, Japan	Research for Mathematical Sciences, Kyoto University Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606
September (tentative)	The 15th International Congress on Microbiology 57-F2,500-J2,500	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc., Daiko Building, 3-2-14 Umeda, Kita-ku, Osaka 530
1990 (tentative)	The 6th International Conference on the Science and Technology of Iron and Steel 50-F300-J500	Japan (undecided)	International Conference Secretariat and Editorial Department, Iron and Steel Institute of Japan 3F, Keidanren Kaikan, 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100
1990 (tentative)	Chemeca 1990 Applied Thermodynamics	New Zealand	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

1991

Date	Title, Attendance	Site	For information, contact
August (tentative)	The 16th International Conference on Medical and Biological Engineering 45-F600-J900	Kyoto, Japan	ME Division, Kawasaki Medical School 577 Matsushima, Kurashiki City, Okayama 701-01
August (tentative)	International Congress on Medical Physics 45-F600-J900	Kyoto, Japan	National Institute of Radiological Science 4-9-1 Anagawa, Chiba 260

1992

1993

Date	Title, Attendance	Site	For information, contact
1993 (tentative)	International Federation of Automatic Control Congress	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

1994

Date	Title, Attendance	Site	For information, contact
Tentative	XXX International Conference on Coordination Chemistry	Kyoto, Japan	Professor Hitoshi Ohtaki, Department of Electronic Chemistry, Tokyo Institute of Technology at Nagatsuta 4259 Nagatsuta-cho, Midori-ku, Yokohama 227

SCIENTIFIC BULLETIN

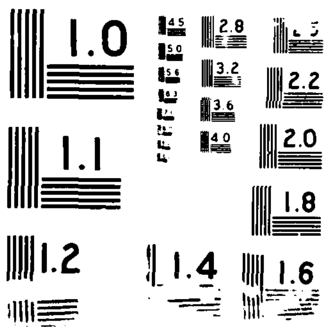
INDEX, VOLUME 12

AUTHORS

SUBJECTS

AD-A194 330 ONR FAR EAST SCIENTIFIC BULLETIN VOLUME 12 NUMBER 4 OCTOBER-DECEMBER 1987(U) OFFICE OF NAVAL RESEARCH LIAISON OFFICE FAR EAST APO SAN FRANCISCO 96503 G B WRIGHT ET AL. DEC 87

UNCLASSIFIED F/G 5/2 NL


1.0
2.8
2.2
3.2
3.6
4.0
2.0
1.1
1.8
1.2
1.4
1.6

INSTITUTIONS/ORGANIZATIONS

LOCATIONS

END
DATE
FILMED
8-88
DTIC